PRELIMINARY ENGINEERING SOILS MAPS FROM SMALL SCALE AERIAL PHOTOGRAPHY

MAY, 1967

NO. 8

by

J.C. HALL

Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

PRELIMINARY ENGINEERING SOILS MAPS FROM SMALL SCALE AERIAL PHOTOGRAPHY

May 11, 1967

TO: G. A. Leonards, Director

File: 1-5-2

FROM: H. L. Michael

Project: C-36-51B

Attached is a Progress Report on the HPR Project "County Engineering Soil Maps." The report is entitled "Preliminary Engineering Soils Maps from Small Scale Aerial Photography" by James C. Hall. The research has been conducted under the direction of Professor Robert D. Miles. The material formed the thesis submitted by Mr. Hall in partial fulfillment of the requirements for the degree of Master of Science.

The report outlines the procedure of making county engineering soils maps using aerial photography obtained at a scale ratio of 1/69,000. Engineering soils maps were prepared by this procedure for Carroll and White counties. This procedure will help to expedite the soil mapping project in the State of Indiana.

The report is presented to the Board for the record and acceptance. It will also be submitted to the Highway Commission and the BPR for review and acceptance.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Secretary

HLM:ss

Attachment

Copy:
F. L. Ashbaucher
W. L. Dolch
W. H. Goetz
W. L. Grecco
G. K. Hallock
R. H. Harrell
V. E. Harvey
J. F. McLaughlin
F. B. Mendenhall
R. D. Miles
J. C. Oppenlander
C. F. Scholer
M. B. Scott
W. T. Spencer
F. W. Stubbs
H. R. J. Walsh
K. B. Woods
E. J. Yoder

Digitized by the Internet Archive
in 2011 with funding from
LYRASIS members and Sloan Foundation; Indiana Department of Transportation

http://www.archive.org/details/preliminaryengin00hall

Progress Report

PRELIMINARY ENGINEERING SOILS MAPS FROM SMALL SCALE AERIAL PHOTOGRAPHY

by
James C. Hall
Graduate Assistant in Research

JOINT HIGHWAY RESEARCH PROJECT

Project: C-36-51B

File: 1-5-2538

Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

Indiana State Highway Commission

and the

U.S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

Not Released for Publication

Subject to Change

Not Reviewed By
Indiana State Highway Commission
or the
Bureau of Public Roads

Purdue University
Lafayette, Indiana
May 11, 1967

ACKNOWLEDGMENTS

The author would like to extend his sincere thanks and appreciation to all those who have helped him and extended encouragement to him before and during the writing of this thesis, and particularly to Professor Robert D. Miles for his help and guidance, to the staff of the Airphoto Interpretation and Photogrammetry Laboratory for their invaluable assistance in the preparation of material and in the final drafting which was necessary, to the Joint Highway Research Project which provided the necessary financial assistance, to previous professors and instructors who contributed to the background which enabled him to undertake this project, and especially to a friend, without whose confidence, patience, and encouragement the project would have come to an untimely halt. To these and the many others who have helped, the author extends his thanks.

West Lafayette, Indiana
August, 1966

TABLE OF CONTENTS

Page

LIST OF FIGURES vi

ABSTRACT vii

INTRODUCTION 1

  Photogrammetry 1
  Photointerpretation 2
  Engineering Soils Mapping 2
  The Need for Change 4
  Purpose 5
  Scope 6
  Previous Research on Small Scale Photography 6
  Previous Contact of Author with Field 8

EQUIPMENT AND MATERIALS 10

  Photography 10
    Small Scale Photography 10
    Large Scale Photography 13
  Maps 15
    Published Topographic Maps 15
    Agricultural Soil Survey Maps 15
    Base Maps 16
  Equipment 16
    Plotter 16
    Pantograph 24
    Coordinatograph 29

PROCEDURES 30

  Compilation 30
    Interior Orientation 30
    Relative Orientation 31
    Absolute Orientation 37
  Interpretation 40

DISCUSSION OF RESULTS 42

  Compilation 42
    Comparison of Relative Orientation Procedures 42

TABLE OF CONTENTS (cont'd.)

Page

Comparison of Absolute Orientation Procedures 43
Interpretation 48
Comparison of Interpretation Procedures 48
Analysis of Photointerpretation Procedures 55
Anaglyphic Projection System 58
Cost and Time Comparisons 59
The Product 61

CONCLUSIONS 63

RECOMMENDATIONS 64

Further Research 65

BIBLIOGRAPHY 68

General References 68

APPENDIX A: THE AIRPHOTO INTERPRETATION OF ENGINEERING SOILS OF CARROLL COUNTY, INDIANA 70

Introduction 70
Description of Area 71
General 71
Drainage Features 73
Topography 74
Geology 75
Land Forms and Engineering Soil Areas 76
Glacial Deposits 77
Fluvial and Glacio-Fluvial Deposits 78
Miscellaneous Deposits 80
List of References 84

APPENDIX B: THE AIRPHOTO INTERPRETATION OF ENGINEERING SOILS OF WHITE COUNTY, INDIANA 85

Introduction 85
Description of Area 86
General 86
Drainage Features 88
Topography 89
Geology 90
Land Forms and Engineering Soil Areas 91

TABLE OF CONTENTS (cont'd.)

Page

Glacial Deposits 91
Fluvial and Glacio-Fluvial Deposits 94
Eolian Deposits 95
Miscellaneous Deposits 96
List of References 98

LIST OF FIGURES

Figure Page

1. Status of Soils Mapping in Indiana 3

2. Small Scale Photographic Coverage of Indiana 11

3. Comparison of the Relative Areas of Coverage of Small Scale Photography, Large Scale Photography and the Platen 14

4. The Double Projection Plotter 18

5. The Variable-Ratio Pantograph 26

6. Critical Positions of Observing Y-Parallax in a Stereoscopic Model During Relative Orientation . . . 32

7. Effects at Critical Positions of Rotational and Translational Movements of Left Projector 33

A1. Location Map of Carroll County 72

A2. Preliminary Engineering Soils Map of Carroll County . . . 81

A3. Location Map for White County 87

A4. Preliminary Engineering Soils Map of White County 99

ABSTRACT

Hall, James Creevey. M.S., Purdue University, June 1967. Preliminary Engineering Soils Maps from Small Scale Aerial Photography. Major Professor: Robert D. Miles.

The research reported is concerned with an effort to improve and expedite the system of compilation of preliminary engineering soils maps from aerial photography. Although the accuracy of these maps, which are used to portray various landform-parent material types and their associated engineering soil groups, was sufficient, it was believed that research in supplemental methods might indicate advantages in time of compilation as well as improvement of techniques. A method of compiling them by photogrammetric means was sought. Due to the large area covered by each map (300 to 500 square miles), it was not feasible to use the common 1:20,000 scale photographic coverage in a plotter due to time and cost limitations. Therefore, the decision was made to investigate the possible use of small scale photography and enlarged stereomodels as developed in a photogrammetric plotter.

Two counties in northern Indiana (White and Carroll Counties) were chosen for this study. Preliminary engineering soils maps of each county were compiled using the small scale (1:69,000) aerial photography flown for the Army Map Service. A double projection plotter of the Kelsh type was used to perform the compilation. Various approaches to the interpretation and identification of the desired engineering soil groups were tried, and a method of approach was developed.

Two conclusions were formed as the result of the research. The first was that except in isolated cases the small-scale photography could be used directly for the interpretation and delineation of engineering soils groups. The second conclusion was that, using certain subsidiary materials, mostly for control, the compilation from small-scale photography of the boundaries of these soil groups on final maps at a scale of 1:63,360 could be readily and reliably accomplished, and that this method was as reliable as previous methods, but could be performed at a considerable savings of time and money.

A system for performing the interpretation and identification of the materials is recommended. A system for performing the compilation is also recommended. Several possible avenues of continuing research are suggested.

INTRODUCTION

In 1860 the first aerial photograph was taken in the United States (2)*. Since then the uses of aerial photography have become too numerous to list, and they have been divided into two sciences. These sciences serve virtually all other sciences or fields of endeavor, from nuclear physics to sociology. These two sciences are photogrammetry and photointerpretation.

Photogrammetry

Photogrammetry has been defined as "the science or art of obtaining reliable measurements by means of photography" (1). Aerial photogrammetry, clearly, delimits the field to apply only to aerial photography. In the aerial form, photogrammetry is used as a method of information retrieval by many different sciences. A nuclear physicist, perhaps, might use it to determine the blast effects of a nuclear device at an inaccessible site; a law enforcement official might use it to determine the average speed of cars on a highway. A geologist could use it to determine the thickness, dip, and strike of some interesting formation. An engineer can use it for many different things. Of particular interest to this project is that the science of photogrammetry, with its laws and mathematical formulae, led to the construction of precise plotters. With these plotters, the information found on aerial photography may be converted into very precise maps both rapidly and reliably.

---

* Numbers in parenthesis refer to the bibliography.

Photointerpretation

"Photographic interpretation is the art of examining photographic images for the purpose of identifying objects and judging their significance" (2). This field, which really is more of an art than a science, is the qualitative complement to photogrammetry. It serves as a tremendously powerful tool in many fields. A sociologist, for instance, might use it to determine the standards of living in various parts of a city; a forester could use it to determine the type and health of individual trees or whole forests. A geologist can use it to determine the nature of the rock; and again, the engineer can use it for many different things. For the purposes of this thesis, however, it serves as a powerful tool for making preliminary appraisal of the nature and extent of various engineering soil materials.

Engineering Soils Mapping

A map which shows both the types of soils found in an area and also their areal extent is very useful for many different types of civil engineering projects. This is particularly true of highways. It is most convenient if these maps are generally available at the very outset of a project.

The Joint Highway Research Project at Purdue University has been developing preliminary engineering soils maps using aerial photography. These maps have been published on an individual county basis or on a specific location for a proposed highway. The county engineering soil maps are published at a scale of 1:63,360, on the polyconic projection. The present status of the program is illustrated in Figure 1.

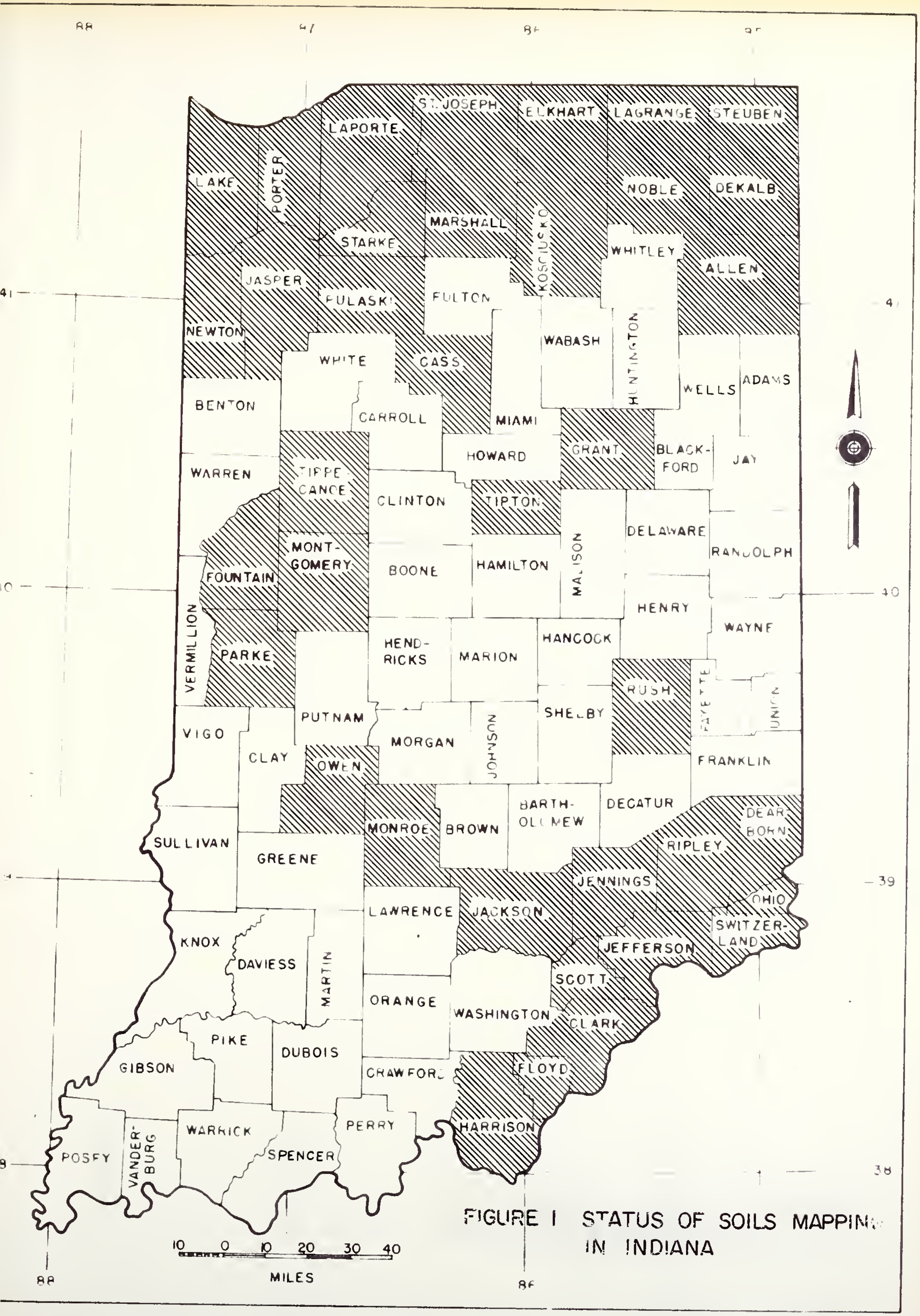


FIGURE I STATUS OF SOILS MAPPING IN INDIANA

The base information on these maps includes the section lines, towns, and major highways. This base map is annotated to show the boundaries of the various landform-parent material groups, and their subdivisions into engineering soil groups. There are two principle techniques presently in use in the compilation of these maps. They both use aerial photography to a certain extent.

In one technique aerial photography is interpreted and annotated to show the boundaries between engineering soil groups. This technique is used in areas where there is little or no supporting information, such as agricultural soil survey maps, available. The boundaries delineated then are transferred to the base maps section by section by projection methods. The photography used is the 1:20,000 scale coverage of the United States Department of Agriculture. As a result of the scale, it takes roughly 250 to 300 photographs to cover the average county.

Another technique is used where recent agricultural soil surveys are available. These soil surveys, which are further described in the next chapter, show the boundaries of all the principal agricultural soil types and phases. With the aid of aerial photographs, these soil types may be grouped by competent engineers into engineering soil groups (the agricultural soil survey maps themselves are compiled using the same aerial photographs as field base maps). The boundaries thus found are outlined on the soil survey maps, and the result is reduced by projection and the boundaries traced on the appropriate base map.

The Need for Change

The above techniques for producing the engineering soil maps are quite reliable. The techniques do require considerable time, however,

as the examination of several hundred aerial photographs or the examination and regrouping of several hundred pedological soil types and phases is time consuming. It may therefore be seen that there is a fairly strong impetus for an improved system of compiling engineering soils maps for the State of Indiana. Several approaches to this problem have been suggested, but they have all either involved the use of the large scale photography, with its numbers problem, or the use of the agricultural soil survey maps, with their problems of limited availability and limited trained personnel.

Purpose

The research which is reported in this thesis had a threefold purpose. The first purpose was to test the feasibility of using small scale photography for the interpretation and identification of landform-parent material groups, and the attendant engineering soil materials, using a variety of systems and auxiliary materials.

The second purpose of the research was to develop a system for producing the preliminary engineering soils maps directly from the small scale photography in a photogrammetric plotter. It was hoped that this one step compilation method would be quicker and at least as reliable as the previous methods, and that it would also be cheaper.

The third purpose of the project was to produce a draft manuscript or manuscripts of some representative area in the state, as a test of the system which would be developed.

Scope

This research was limited in several ways. The first limitation which was placed on it was that the research would apply only to a rather small area. This was done so that the area could be readily visited and the ground truth determined. The area chosen, which was just under 1,000 square miles in extent, was Carroll and White Counties in northwestern Indiana.

The second limitation which was placed on the research applied mostly to the second objective. The investigation of compilation techniques would be limited to the photogrammetric equipment available in the Airphoto Interpretation and Photogrammetry Laboratory at Purdue University. The equipment which was used is discussed in the next chapter.

The third principle limitation was that only photography which was already available to the general public would be used in the investigation. This limitation applied both to the photography used as the mapping medium and to the photography and materials used in the process of interpretation, delineation, and identification. Two scales of photography were used in the investigation. The two scales available were small scale photography, described in the next chapter, to be used for both mapping and interpretation, and the large scale photography, which is also described in the next chapter, which would be used to supplement the small scale photography for interpretation in some experiments.

Previous Research on Small Scale Photography

The use of photography at small scales is a relatively new development. It was not until after World War II that aircraft capable of flying

at the altitudes necessary to obtain this type of coverage were developed for commercial use, and it was some time after that that they began to be used for photographic purposes.

Small scale photography was used extensively for mapping purposes in 1952 and later, when the United States Army Map Service used small scale photography in the compilation of the 1:250,000 scale 1° by 2° map set of topographic maps. These topographic maps are available from the U.S.G.S. for the entire United States. They were compiled by photogrammetric methods in large part, with only a minimum of ground surveying required for control and detail.

Small scale photography has also been used as an interpretive device, particularly in the field of geology. In this area it has been used both for interpretation and mapping, in much the manner which was proposed for investigation in this thesis. Mr. Richard G. Ray of the United States Geological Survey reported, in 1956,

> "One of the most recent and promising developments in photogeology with the Geological Survey is the application of photography taken at altitudes as high as 35,000 feet, termed high altitude photography (scale of 1:60,000 to 1:70,000, and commonly about 1:63,360 or 1 inch to a mile), for use by the Army Map Service in the 1:250,000 scale topographic compilation of the United States. In the Kelsh plotter, this photography effects a model scale of about 1:12,000, and the estimated error in measuring vertical distances is 5 to 6 feet under optimum conditions. Because this photography is of small scale, some of the minor details of the terrain are difficult to distinguish in the stereoscopic model, but in areas suited to photogeologic study this loss of detail is generally not a deterrent in interpretation and mapping" (5).

The idea of using this smaller scale coverage for geologic work, instead of the more common 1:20,000 scale Department of Agriculture photography, rapidly gained momentum, and in 1961 Dr. Victor C. Miller said, in regard to photogeologic interpretation,

> "The trend toward the increased use of precision measuring and plotting instruments, such as the Kelsh Plotter, has created a greater demand in the United States for smaller-scale photography. It is believed that in such work a scale of about 1 mile to the inch is optimum" (3).

Mr. Ray and Dr. Miller are both referring to coverage flown with a six-inch focal length lens, as up until very recently this was the shortest focal length lens available for precise mapping work. More recently, however, a series of new lens formulae has produced lenses of three inch or even shorter focal lengths, capable of covering the nine inch by nine inch standard aerial photographic format. These new lenses are known as super wide angle lenses. These lenses and the photography taken by them have certain theoretical and actual advantages from mapping or interpretation, as well as several rather notable disadvantages.

In spite of all the activity in the field of photogeologic interpretation and mapping with the small scale photography, very little information concerning the use of small scale photography for engineering purposes, such as the preliminary soils maps, could be found. This is possibly because of an emphasis within engineering on the more detailed surveys, such a final maps at a scale of 1:600, at the expense of regional maps at a scale of 1:60,000 or so. Small scale coverage is not very well suited for large scale mapping. The author, however, could find no theoretical reasons for not using the small scale coverage in preliminary mapping, particularly in view of its apparent success in the field of geology.

Previous Contact of Author with Field

The author became interested in the field of photointerpretation in general and photogeology in particular in 1963, when he took a course in

this field as a part of his undergraduate major in geology. This course included only the most elementary photogrammetry, but was focused primarily on the interpretation of igneous and metamorphic rocks. He found that the small scale photography was advantageous in this work.

Upon graduation with a degree of Bachelor of Arts, the author assumed a position as a cartographer with the United States Air Force, Aeronautical Chart and Information Center. While there he was assigned to the Cartography Division, and began training as a photogrammetrist. Upon completion of this training, he was assigned to train other men in the techniques of using photogrammetric instruments, particularly several varieties of double projection plotters. He also undertook some work with photointerpretation on small scale to very small scale photography. He was impressed with the capabilities of small scale photography.

EQUIPMENT AND MATERIALS

Photography

Aerial photography was the basic source material for this project. All of the photography used is readily available; no new coverage was required or flown.

Small Scale Photography

The principle source material for the mapping in this project was small scale photography. The coverage which was used is part of an almost nationwide program which was flown for the Army Map Service by various companies. The photography, in the form of glass diapositives, contact prints, enlargements, and index mosaics, is available from the Army Map Service or the United States Geological Survey, Department of the Interior. In addition, small maps showing the various project areas are available, such a Figure 2, which illustrates the coverage available for the State of Indiana. The photographs used in this project were a part of area 95-A and include coverage of Carroll and White counties.

Small scale photography has a number of definitions. For the purposes of this report, however, it may be defined as aerial photography with a scale smaller than 1:50,000. In this particular case, it has a scale of about 1:69,000. At this scale, which is a little smaller than one mile to the inch, each side of the nine inch by nine inch diapositives represented about ten miles. This gave a total area per diapositive

AERIAL PHOTOGRAPHY OF THE GEOLOGICAL SURVEY

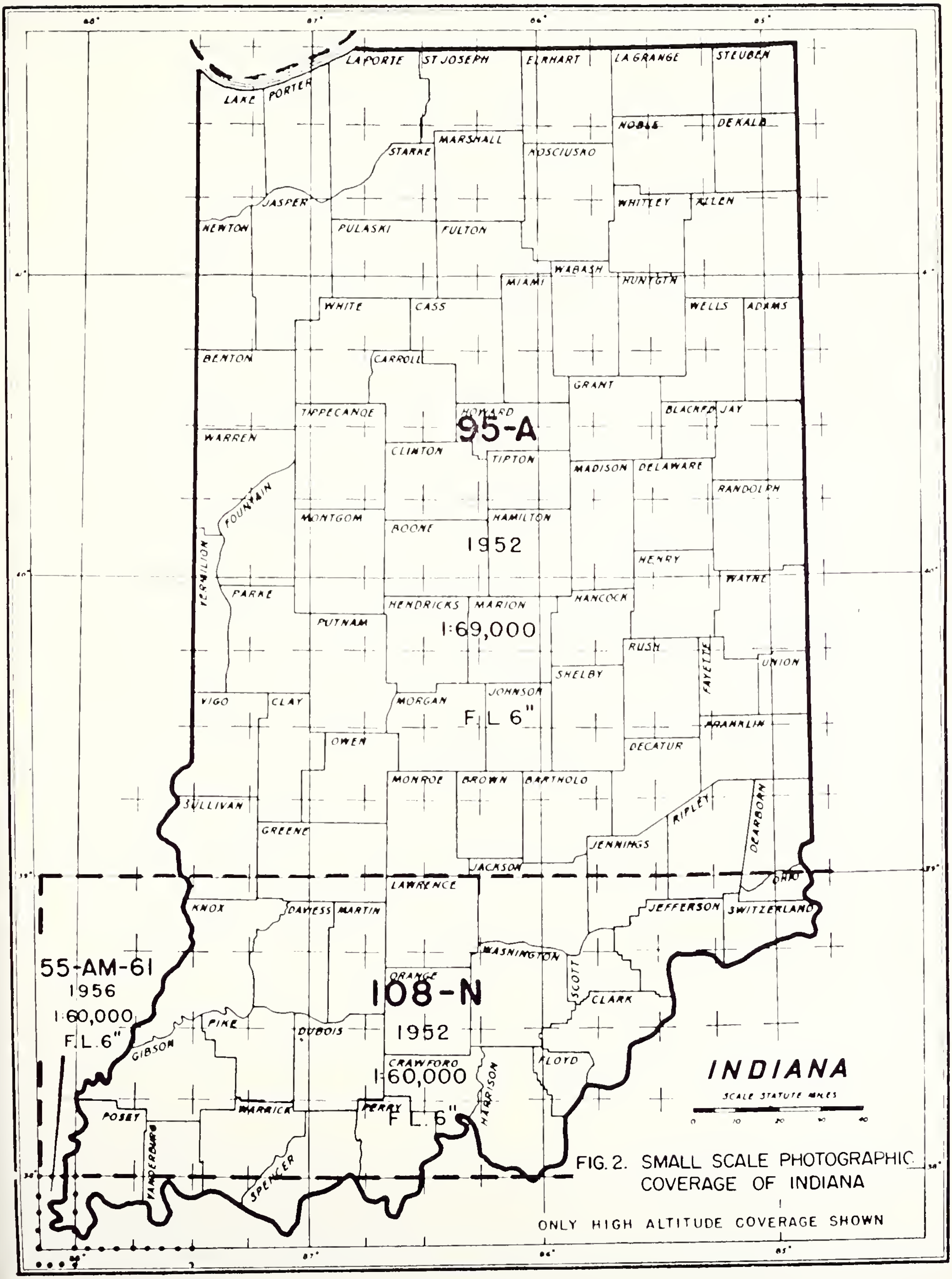


FIG. 2. SMALL SCALE PHOTOGRAPHIC COVERAGE OF INDIANA

ONLY HIGH ALTITUDE COVERAGE SHOWN

of about 100 square miles. The coverage was flown in 1952 at an altitude of about 35,000 feet above mean sea level, and the lens used was a six-inch focal length Metrogon type. It was flown originally for the Army Map Service's program of mapping the United States at a scale of 1:250,000 in 1° by 2° charts. As such, this photography conforms to very high standards with respect to distortions and variations in orientation.

The aerial photography for this project was obtained in two forms; as the familiar contact print, which is printed directly from the negative onto paper, and also as glass diapositives. In the latter case, the copy emulsion, instead of being supported by a piece of paper, is supported by 0.250 inch thick glass plates which are manufactured to very close tolerances (0.060 inch thick plates are also available). These plates serve to hold the imagery stable in size and shape in spite of variations of temperature and humidity. Forty-two photographs were needed to cover the area, and one contact print and one glass diapositive of each negative were obtained.

Upon checking the photography, it was found that its scale was exceptionally uniform. The photography was also found to be substantially free of tip, tilt, and swing, which are three rotations around the camera's axes. The approximate overlap was found to be very close to the nominal 60 percent, and the sidelap also agreed well with the nominal figure of 25 percent. It was noted that the cloud coverage visible on the index mosaic was zero within the State of Indiana.

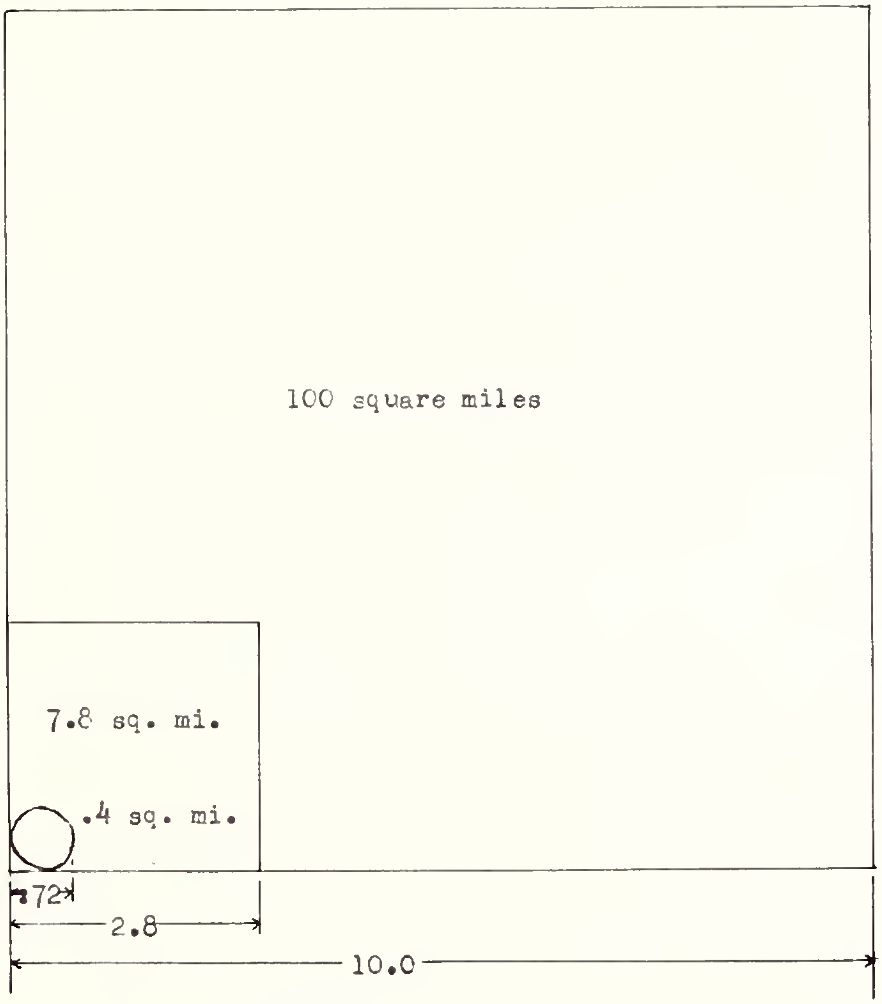
Large Scale Photography

Large scale photography, for the purposes of this thesis, may be defined as aerial photography which has a contact scale larger than 1:50,000. The particular photography used in this project and referred to as large scale is the 1939 coverage of Carroll and White Counties at a contact scale of 1:20,000. The photography is held by the Agricultural Stabilization and Conservation Service of the United States Department of Agriculture. The index mosaics, contact prints, and enlargements of this photography may be obtained from the Eastern Laboratory, Aerial Photography Division, ASCS-USDA, 45 South French Broad Avenue, Asheville, N. C. Information on glass diapositives should be obtained from the United States Geological Survey. Coverage is available for most of the United States at many dates, as an effort is made to refly each area from time to time.

This particular large scale photography is in the format of seven inch by nine inch contact prints. It was found on examination of the prints that their quality was not as high as that for the small scale photography. Due to the scale, the area covered by each print is much less than the area of the small scale prints, as is illustrated in Figure 3, which shows the relative areas of the platen, the large scale prints, and the small scale prints. The photography was obtained using an 8-1/4-inch focal length camera lens. It was found that the scale of the photography was reasonably constant. Due to the small area of coverage on each print, over 500 photographs were required to obtain complete coverage of the two counties; an actual count was not made. Prints of this coverage for the entire State of Indiana are available at Purdue University.

---

* Both scales shown as nine inch squares at photo scale.



Dimensions in miles

FIGURE 3. Comparison of the Relative Areas of Coverage of Small Scale Photography, Large Scale Photography, and the Platen

Maps

A number of maps were involved in this project, as reference material or as control. These include topographic maps, the Agricultural Soil Survey Maps, and the two base maps for the compilation.

Published Topographic Maps

Maps from two series of topographic maps covering the United States were used in this project. The 1:250,000 scale 1° by 2° map set was represented by the Danville map (NK 16-11). This map was used principally for determining the location of particular photographs, and was also used for naming and locating certain cultural features.

The 1:24,000 scale, 7-1/2 minute series of topographic quadrangle maps was also represented. These maps, which have a contour interval of either 5 feet of 10 feet in this area, were used primarily for control. They are available over the entire area of Indiana.

Agricultural Soil Survey Maps

The Soil Conservation Service of the United States Department of Agriculture publishes a series of maps, at various scales, of many of the counties in Indiana. These maps show information about the agricultural soils which may be found in any given county; they are accompanied by reports giving data on these soils. Some of this series are quite recent. Some of the maps and reports, however, are quite old and not too useful. The maps were used in this project for helping to interpret the soils which were found, although the White County map was very old.

Base Maps

The base maps for this project were traced from the drainage maps of the two counties. They were at a scale of about 1:63,360, and drawn on the polyconic projection; the same scale and projection as the desired final maps. The map of Carroll County showed the section lines, towns, and the major streams. The map of White County showed the State and Federal highways in addition to the section lines, towns, and major streams. These maps were drawn on tracing paper. They served as bases on which to delineate the engineering soil boundaries as they were found, and also as a source of horizontal control for the models.

Equipment

Three pieces of equipment were used in this project; a double projection plotter of the Kelsh type, a pantograph made for attachment to the plotter, and a coordinatograph.

Plotter

The purpose of the plotter is to provide an analogue solution of the photogrammetric problem. The principle of this plotter and the many others which are similar to it is to create an exact scale reconstruction of the relation between the cameras at the moment of exposure, and then, by projection, to create a scale model of the terrain photographed. This model, which is theoretically free of all distortions, is then traced onto a mapping sheet in a true orthographic projection. There are four major divisions of the plotter, which is illustrated in Figure 4.

Illumination and Projection System. The illumination and projection system which is used is unique to this type of plotter. The illumination

FIGURE 4. The Double Projection Plotter

1. Lamphouses
2. Glass Diapositives
3. Plateholders
4. Projector Cones
5. Lens Barrel and Lens Calibration Ring
6. bX Knob
7. Swing Knob
8. Tilt Screw
9. Tip Screw
10. Space Rods
11. Tracing Table Gearbox
12. Platen
13. Tracing Table
14. Drafting Surface
15. Main Frame
16. Leveling Screws
17. Support Frame
18. Leveling Frame
19. Height Adjusting Screw
20. Lamp Control Box
21. Pantograph
22. Rails

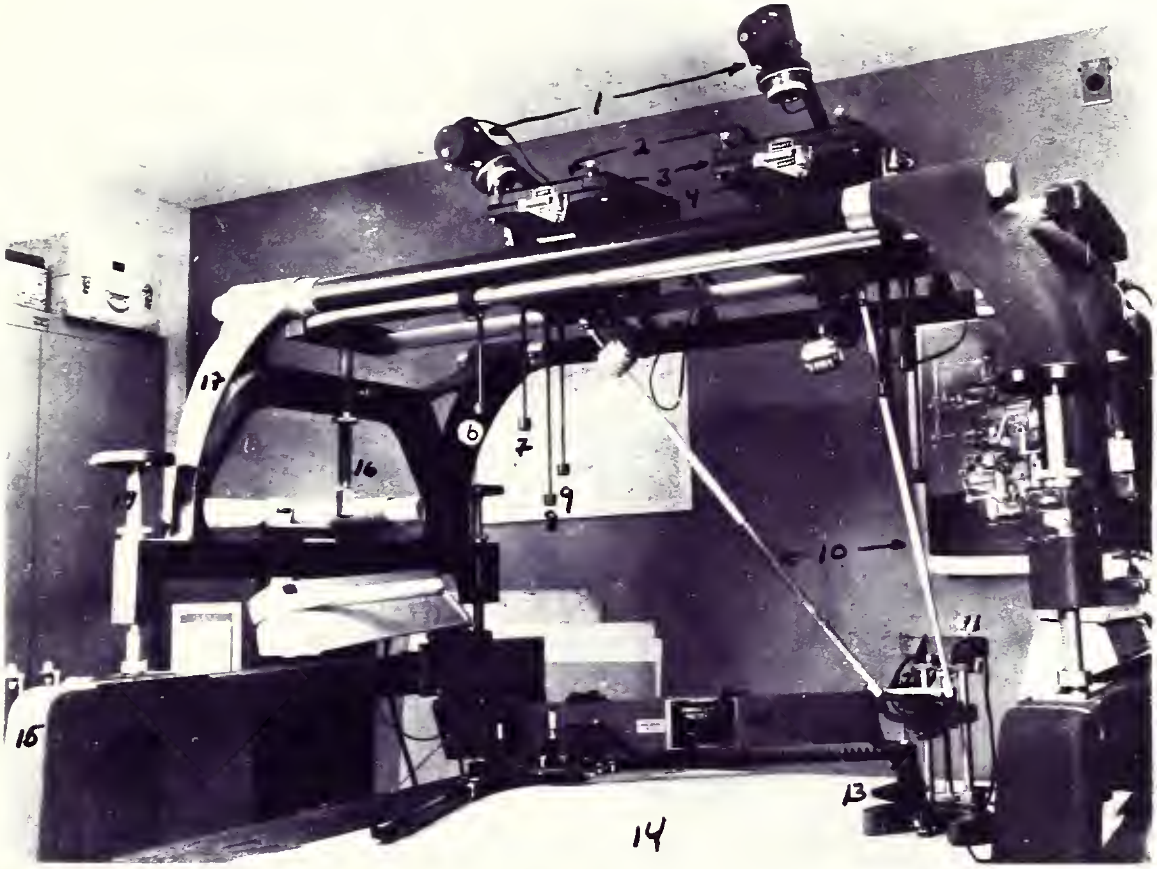


FIGURE 4. The Double Projection Plotter.

is provided by 12-volt bulbs in the lamphouses (Number 1, Figure 4). In order to obtain a maximum amount of illumination evenly spread over the model, without the necessity of using large condensing lenses or mirrors, this type of plotter uses a system in which only the area of the diapositive which is actually being viewed at any given time is illuminated. This concentrates the available light on only 0.4 percent of the total area of the diapositive, increasing the brightness by a factor of about 200 over what it would be if the same bulb were used to illumine the whole diapositive at once. These lamphouses are equipped with red or green filters, which form a portion of the viewing system.

The illuminated glass diapositives are then projected by the lens. In order to exactly reconstruct the ray paths which were present in the taking camera, the lens and diapositive must be held in exactly the right orientation to each other. In order to accomplish this, the diapositive is clamped in the plateholder (Number 3), which contains the fiducial (index) marks used to center the plate. The plateholder in turn rests on four screws in the cone (Number 4). The cone, in its turn, is mounted securely on the lens barrel (Number 5). This combination of parts makes up the basic projector. However, it is desirable for certain types of photography to be able to correct for radial distortions on the diapositives. This is done on this type of plotter by means of aspheric cams in the lens mounts. These cams vary the vertical position of the lens with respect to the plate in a systematic way, the amount of raising or lowering being determined by the angle of the projected ray with the principal axis of the lens. These cams are controlled by the space rods, Number 10, which are linked so that they are always parallel to

the projected ray. In order to ensure that the proper portion of the diapositive is illuminated, the lamphouses are mounted on extensions of the space rods. The scale of the projected model is approximately five times larger than the scale of the diapositives.

The Viewing System. The images produced by the two projectors are viewed on the platen (Number 12). In order to view an object in stereo, it is necessary for each eye to view the object from a slightly different angle. The two photographs, which were taken in different positions in space, serve this purpose; all that is needed is to channel the proper photo image to the proper eye. This is accomplished in this type of plotter by a system known as the anaglyph. In this system the two photos are projected in complimentary colors. The operator of the plotter wears glasses in the same two colors, matching the color of the lens over the left eye to the color of the left photograph. The colored lenses block the image of the opposite photo, and thus only the proper photo reaches each eye and the model may be seen in three dimensions. Although the whole model is theoretically there, due to the construction of the illumination system only a small portion of the model (actually a circle three and one quarter inches in diameter) is illuminated and may be viewed at any one time.

The controls for the illumination system control the intensity and the focus of the lamps. The intensity, which must be frequently adjusted as the tracing table is moved over the model, is controlled by rheostats on the right side of the main frame in Figure 4 (Number 20). There is one rheostat for each lamp. The focus of these lamps, which normally requires adjustment only after a lamp has been changed, is controlled by system of knobs and screws located on the lamphousing.

The Measuring System. Some means must, of course, be found to record the information contained in the assembled and viewed model. On this type of plotter, this is accomplished by means of the tracing table (Number 13) and a recording sheet placed on the drafting surface (Number 14). When the model is viewed, a small illuminated spot, termed the "floating mark", which is 0.01 inches in diameter, may be seen in the center of the platen. This mark appears to occupy a position in space, and may be moved vertically by means of a lead screw in the tracing table or horizontally by moving the whole table. To record the Z-axis (see Figure 4 for the orientation of the axis) coordinate of a point on the model, the motion of the lead screw is transferred by variable gears in the gearbox of the table (Number 11) to a digital counter. These gears provide a wide choice of ratios. By a proper choice of the ratio, determined by the model scale, the counter may be made to read the elevations of points on the model directly in feet. Since the model is free of the perspective distortions in the photos, the X and Y coordinates of the point on the model are the correct ones, to scale, which would be found on the ground. These may be transferred orthogonally to the drafting surface by means of the table and a pencil point which is mounted vertically beneath the floating mark. By means of this pencil the operator may record the true locations of points found on the model, or he may trace out roads or streams, or by holding the floating mark at a constant elevation and following the terrain he may trace out contour lines. In the situation when a pantograph is used, the pencil is simply replaced by the pivoting connection for the pantograph.

The Controls. There are a number of controls on this type of plotter. In order to properly describe them, however, a look at the axis of the machine would be in order (Figure 4).

The system of axis which is used is based on the usual rectangular coordinate system. In this plotter the X axis is directed parallel to the line joining the two lenses. The Y axis is perpendicular to the X, and lies in a horizontal plane. The Z axis is perpendicular to the other two. There are three rotational movements of the projectors to be considered. These are called in this report tip, tilt, and swing. Tip refers to projector rotations around the Y axis. Tilt is the term applied to rotation around the X axis. Swing refers to rotation of the projector around the Z axis.

The controls associated with orientation are best subdivided into three groups; those involved in interior orientation, or the alignment of the diapositive and the lens in one projector; those for relative orientation, or the alignment of the two projectors with respect to each other; and those for absolute orientation, or the adjustment of the model to fit a datum.

The controls affecting interior orientation are normally set once for a project and then left unchanged. They are the cam, which is selected to suit the photography or may be deactivated, and the calibrated focal length adjustment of the projector, which is set by a ring around the lens barrel. This is adjusted to agree with the known equivalent focal length of the lens used to take the original pictures. The centering of the fiducial marks and the calibration of the calibrated focal length are both controlled by various small screws; these require special laboratory equipment to adjust and are not normally touched.

There are three controls on this type of plotter which are used in the process of relative orientation. They are the swing knob (Number 7), the tilt screw (Number 8), and the tip screw (Number 9). Turning each of these causes rotation of one projector around the appropriate axis to achieve the relative orientation of the projectors. There is one set of these controls for each projector.

Absolute orientation may be divided into leveling and scaling. Basically, the scale of the model is equal to the ratio of the distance between the lenses of the plotter to the distance between the exposure stations of the taking camera. The distance between the projectors is adjusted by moving the projectors along their support rails (Number 22) in the X direction; coarse movement is done by loosening a clamp and sliding one or the other, but fine motion is accomplished by the bX knob on either projector (Number 6). Leveling is performed by rotating the entire model; this is accomplished by rotating the frame which supports the projectors. This frame is held by the three leveling screws (Number 16) which are turned to level the model. The methods for scaling and leveling will be explained in the next chapter.

There are several other controls available to the operator on this type of plotter. One is a small knob, (not shown) called the bY knob which can move either projector a short distance along the Y axis to correct minor errors in orientation. Another is the elevation wheel and gear ratio mechanism in the tracing table, and the last is a rheostat mounted on the tracing table which controls the brightness of the floating mark. In addition, there are several adjustments on the tracing table which are set once and then just checked; these control the centering of the pencil chuck and the verticality of the frame.

Pantograph

The pantograph attachment to the plotter (Number 21, Figure 4 and Figure 5) serves to reduce the motions of the tracing table as it is moved over the model to the desired scale of the final map. This saves a drafting step in the compilation, if it is otherwise necessary to perform the reduction in some sort of reducing projector, or it eliminates a photographic reduction step, which is expensive and requires somewhat sophisticated copy cameras. This pantograph was purchased for this project, and is designed to fit the plotter used.

Description. The pantograph is basically a very simple device. It accomplishes the reduction using the principle of similar parallelograms. Ideally the center of the pencil (Number 7, Figure 5) is directly on the line joining the main pivot bearings (Number 11) and the bushing for the tracing table (Number 9). The reduction ratio is determined by the ratio of the distance from the main pivot bearing to the pencil to the distance from the main pivot bearings to the tracing table bushing. This pantograph is of the suspension variety; that is to say, it is supported from one set of bearings. The main arm (Number 2) carries the table arm (Number 3) and the side arm (Number 4). The tracing arm (Number 5) is supported by these two arms, and it in turn supports the pencil control solenoid (Number 6) and the pencil (Number 7). These three arms carry engraved scales, and the tracing arm has a vernier at each end which reads on the scales on the table arm and the side arm. The pencil assembly also has a vernier which reads on the scale on the tracing arm. The pencil is raised or lowered by a switch near the table bushing (Number 10).

Figure 5. The Variable-Ratio Pantograph

1. Support Bracket
2. Main Arm
3. Table Arm
4. Side Arm
5. Tracing Arm
6. Pencil Control Solenoid
7. Pencil
8. Level Vial
9. Tracing Table Bushing
10. Pencil Control Switch
11. Main Pivot Bearings
12. Verniers
13. Bracket

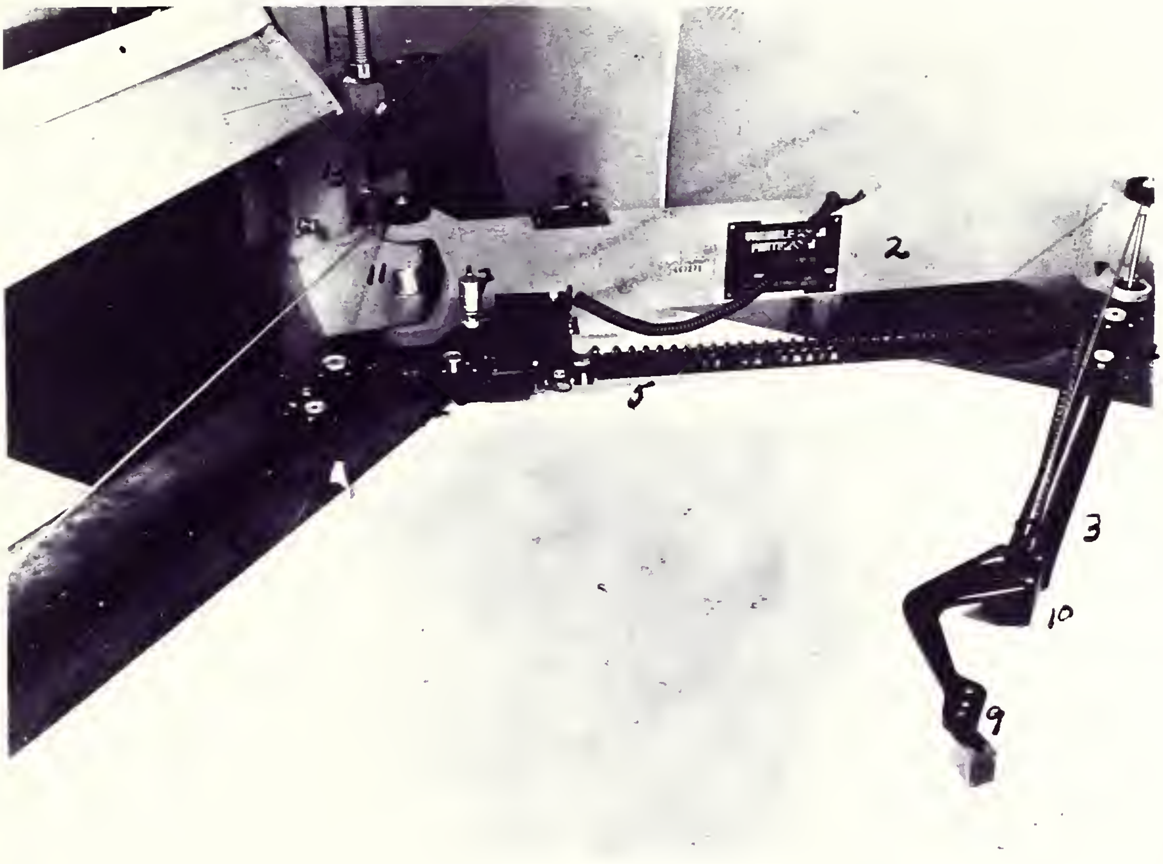


FIGURE 5. The Variable-Ratio Pantograph.

Pantograph Adjustment. The pantograph is calibrated and adjusted, normally, at the beginning of the project and then is not changed as long as the reduction needed remains the same. The first step in this procedure is to make absolutely certain that the pantograph moves in a plane parallel to the drafting surface. Every effort is exerted to have the drafting surface exactly level; therefore the pantograph may be set in a parallel plane by simply leveling the arc of the main arm. For this purpose the main arm carries a level (Number 8). Using two adjustable pivot bushings, found on the bracket (Number 13) on either side at the top, the main arm is set level when extended to the rear and to the front as seen in Figure 5. The arm is then extended to the position illustrated, and is leveled in this position using an adjustable shim at the bottom of the bracket. The leveling is then rechecked, and readjusted; due to a certain amount of interaction between the shim and the pivot bushings this is a repetitive operation which is continued until the operator is satisfied. There is a second level placed across the main arm; this is not to be used, and is installed only for calibration at the factory.

The second step in the adjustment procedure is to determine the desired reduction number and from that to determine the proper settings of the verniers (Number 12). The desired reduction number is equal to the model scale divided by the map scale. To determine the vernier setting, this number is divided into 840. The pantograph is capable of reductions between about 1.5:1 and 5.5 to 1. The number resulting from the division is set on all three verniers, which have a double lock screw arrangement with a coarse nut which may be loosened for large movements or clamped for fine motions. It is extremely important that all three

verniers be set to exactly the same number, as otherwise the reduction will not be even in all directions. It is better to accept a reduction number which is not exactly the one desired in order to obtain a vernier setting which does not require interpolation. These settings should be checked now and then during compilation.

The third step in the adjustment is to place the pencil lead so that it clears the drafting sheet when mechanically raised; this is an ordinary drafting mechanical pencil which is easy to adjust. The weight on the pencil is adjusted so that it marks properly; this last is accomplished by using ring-shaped weights which slip over the pencil itself; the minimum amount of weight necessary should be used. The pencil lead should be sharpened with special care taken to ensure the centering of the point.

Checking. It is advisable to check the adjustment of the pantograph both prior to using it and also during its use from time to time. This is best accomplished by establishing two diagonals in the model area. These should be approximately at right angles to each other, in order to check the reduction in all directions. They should be very accurately measured, preferably with a precise meter bar. It is very convenient if they are of exactly the same length, and also exactly one meter long. These diagonals are then traced out with the tracing table, which must be previously adjusted, and the reduced lines measured. They should agree in length with each other within 0.1 millimeter. The reduction ratio may be computed by dividing the length of the original line by the length of the new line. If the two diagonals do not agree, the adjustment procedure should be repeated with care to determine where the error lies.

Coordinatograph

The coordinatograph (not illustrated) was used in one experiment. The purpose of this device is to provide a digital reading of the plane rectangular coordinates of a known point in relation to some Cartesian system, or conversely to plot the location of a point whose X and Y coordinates are known. In this particular experiment the coordinatograph was used to determine the state plane coordinates of selected points and subsequently to plot them on a control sheet.

The coordinatograph consists of three main parts; the table track, the bridge, and the carriage. The table track is very accurately straight, and is affixed to the surface being used. The bridge is supported on one end by the track and on the other by a wheel. On the end which is supported by the table track a small pinion engages a rack on the table track. The pinion turns a disc on which may be read the distance of the bridge from one end or the other of the track. There is a similar track and rack on the bridge, and the carriage, which holds the pencil or microscope, rides along this track, which is at right angles to the first. There is a similar disc and pinion set on the carriage, which indicates the distance the carriage is along the bridge. Thus from these two discs the X and Y coordinates of any point may be measured.

The set up of this instrument demands only that it be assembled with care, making sure that the pinions engage the racks properly, and placing the appropriate discs on the machine. Discs are available for several scales, as well as for direct readings in inches or meters.

PROCEDURES

Compilation

Several variations on the basic procedure for compilation with the double projection plotter were tried in the course of this research in an effort to determine the best system. The procedures which were used are best divided according to the stages of orientation and compilation (1).

Interior Orientation

Interior orientation is the term applied to the process of reproducing the precise geometrical relationship between the imagery on the diapositive and the projector lens as existed between that imagery and the lens of the taking camera. This is accomplished by aligning the fiducial marks on the diapositive with the index tabs found on the plateholder (Number 3, Figure 4), which indicate the location of the principal point of the projector. The fiducial marks were printed on the negative at the time of exposure and indicate the location of the principal point of the negative. The four clamp screws on the plateholder are tightened enough to hold the diapositive securely without strain. The plateholder is then placed on the cone (Number 4, Figure 4) of the projector. The adjustment of special support screws is such that when the plateholder is firmly in position the correct geometric relationships with respect to the lens are established. Since this is a fairly straightforward procedure, no variations were tried.

Relative Orientation

Relative orientation is the process of recapturing with the projectors the geometric relationship between the camera positions at the times the two negatives were exposed. The rays of light from each projector, which correspond to a given point on the diapositives, should meet in a single point. Lack of correspondence produces a double image effect with the displacement in the Y direction.

Two procedures of relative orientation were used. The two methods which were used are the swing-swing method and the rationalization method, modified (1). In order to properly follow the two procedures it is advised to refer to Figures 6 and 7. Figure 6 illustrates the scheme of numbering critical positions in the model area. Figure 7 shows in what direction and relatively how much an image point at each critical position will move when the various controls of the left projector are turned. It may be seen from this figure that swing causes the points to describe circles around position one, tip causes the points to move in X and, at positions three and five, slightly in Y, and tilt causes the points to move mostly in Y, with some slight X motion at positions three and five.

The Swing-Swing Method. The swing-swing method is one method of accomplishing relative orientation. It should be explained that an image displacement in the X direction, termed X parallax, is removed by moving the platen in elevation or by moving the projectors in bX translation. Image displacements in the Y direction, termed Y parallax, are removed by the swing-swing method or by its alternate, the rationalization method as modified. The presence of Y parallax indicates that the relative orientation of the two projectors is not complete.

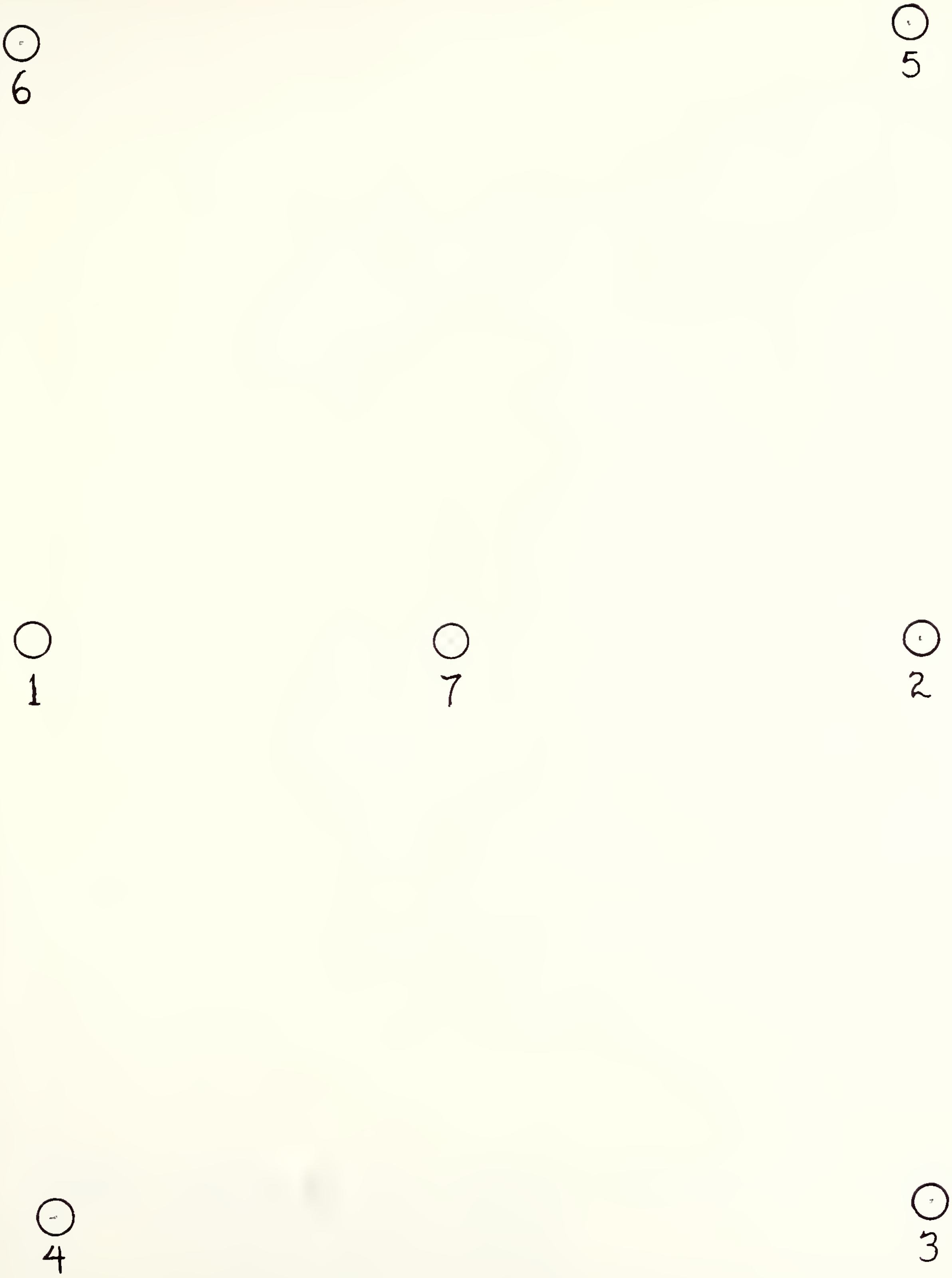


FIGURE 6. Critical Positions of Observing Y-Parallax in a Stereoscopic Model During Relative Orientation.

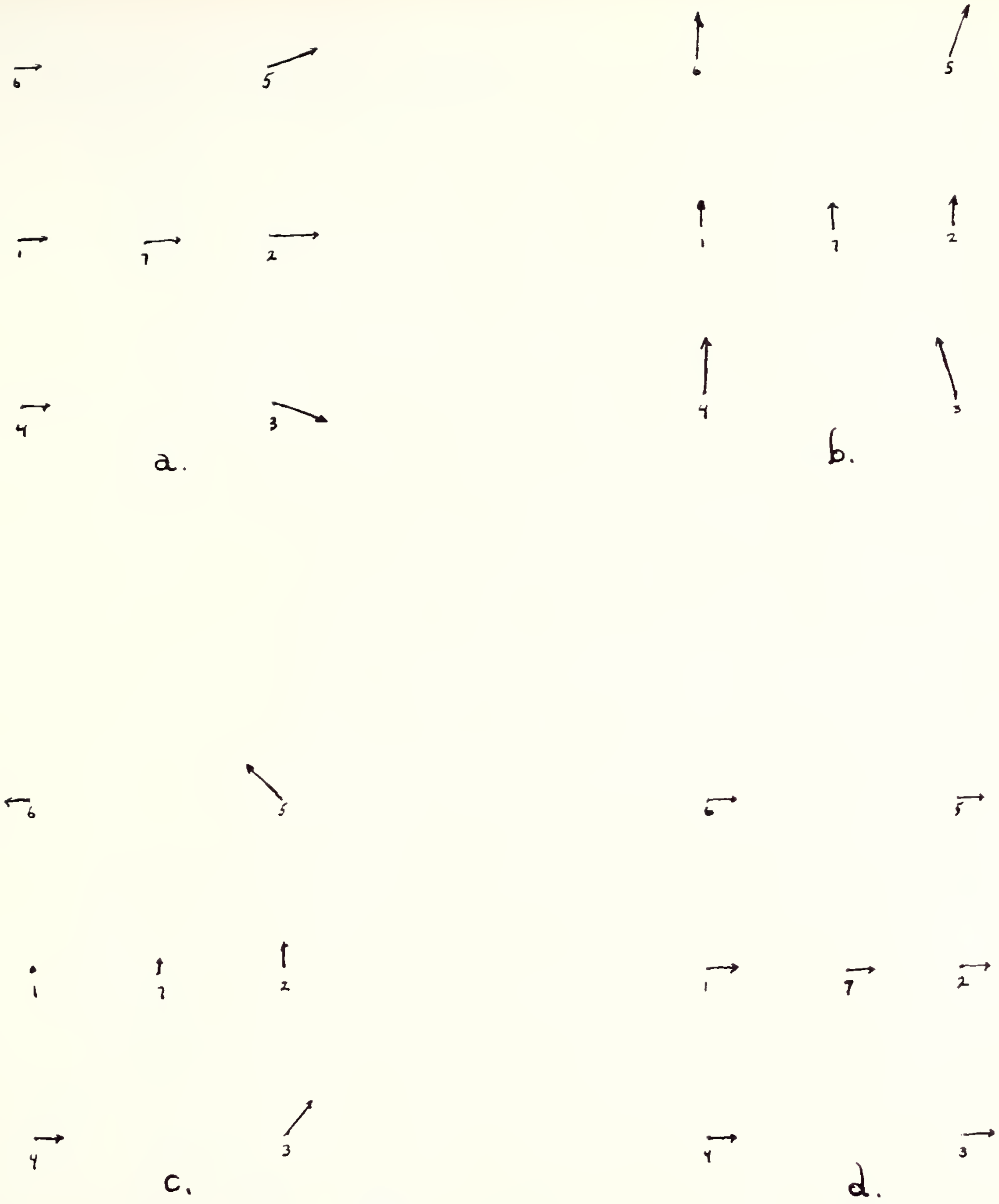


FIGURE 7. Effects at Critical Positions of Rotational and Translational Movements of Left Projector.

a. Tip Screw, Left Projector
b. Tilt Screw, Left Projector
c. Swing Knob, Left Projector
d. bX Knob, Left Projector

The steps in the swing-swing method are as follows:

1. Select a well-defined object near position one (Figure 6). Using the swing knob (Figure 4) of the right projector, remove the Y parallax at this position.
2. Select a well-defined object near position two. Using the swing knob of the left projector, remove the Y parallax.
3. Repeat steps one and two until the Y parallax at both position one and position two is reasonably eliminated.
4. Select a well-defined object near position three. Using the tip screw (Figure 4) of the left projector, remove the Y parallax at this position. Since the motion is principally in X at this point (Figure 7), it is necessary to change the elevation of the platen as the tip screw is turned in order to keep the X parallax zero. Should the displacement go beyond the range of the tracing table, the projectors may be moved in the X direction on their rails to correct for this.
5. Repeat steps one through four until the parallax is essentially removed at positions one through three.
6. Select a well-defined object near position four. Using the tip screw of the right projector, remove the Y parallax at this position. Again, as in step four, the elevation will change and the projectors may have to be moved again.
7. Repeat steps one through six until the Y parallax is essentially eliminated at positions one through four.
8. Select a well-defined object near position five. Using the tilt screw of the right projector, move the image so that the

parallax is in the opposite direction and about one and one half times as great when finished as it was before starting this step. It is possible to interchange positions five and six, and use the tilt screw of the left projector. At no time, however, should both tilt screws be used during the course of relative orientation; choose one and stay with it.

9. Repeat steps one through eight until the parallax is essentially eliminated at positions one through five.
10. Move the tracing table to position six. The presence of Y parallax at this point indicates an imperfect solution. This should be corrected by repeating steps one through nine with great care until all Y parallax has been eliminated. Any remaining Y parallax will warp the model and cause errors in elevation and horizontal positioning.

Most experienced operators perform the first two or three runs through this routine without using the colored glasses. The final stages of removing the parallax may be done with or without the glasses as the operator prefers.

The Rationalization Method, Modified. The rationalization method, modified, is another method used to perform relative orientations. This method requires a knowledge of the motions of the points induced by turning the tip and tilt screws and the swing knob. These are illustrated in Figure 7. The steps to be followed in this method are:

1. Select a well-defined object near position seven. Using the tilt screw of the right projector, remove about half of the Y parallax. Remove the remaining parallax by using the tilt screw of the left projector.

2. Select a well-defined object near position one. Remove the Y parallax by using the swing knob of the right projector.
3. Select a well-defined object near position two. Using the swing knob of the left projector, remove the Y parallax.
4. Repeat steps two and three until the parallax is essentially removed at both position one and position two.
5. Move the tracing table to position five and then to position three. Observe the Y parallax at these two positions. With the knowledge of the movements which result from turning the tilt screw of the right projector or the tip screw of the left projector, decide about how much of each should be used. Perform the needed corrections.
6. Repeat steps two through five until the parallax is essentially removed at positions one through three and position five.
7. Select a well-defined object near position four. Remove the Y parallax using the tip screw of the right projector.
8. Repeat steps two through seven until the Y parallax at positions one through five is essentially removed.
9. Move the tracing table to position six. The presence of Y parallax at this position indicates that the solution is not perfect. Steps two through eight should be repeated until all the positions are free of Y parallax. Any remaining Y parallax will cause warpage of the model, and throw elevation readings across the model off.

As in the swing-swing method, the first stages of this method are usually done without using the glasses. Final touching up, however, may be done either with them or without them at the operator's option.

This method takes some practice to become comfortable for an operator, however, it is quite rapid with good photography. In the initial stages of learning the process, constant reference to the diagrams in Figure 7 will be found to be useful.

The last caution is that again the tilt screw of only one projector should be used except in the first step.

Absolute Orientation

Absolute orientation is the term used to describe the process of adjusting the model formed by the relative orientation to the desired scale and also adjusting it so that the elevations may be read correctly. These phases are termed scaling and leveling, respectively. The usual procedure is to perform approximate leveling, then scaling, and then exact leveling.

Leveling. The leveling for this project was performed in two steps; leveling in Y and leveling in X. Before leveling is done, however, at least three and preferably four points should be identified in elevation. These points should be located near positions three through six, and should be such that they can be measured on the model with great accuracy. Road intersections are ideal. After these points are selected, leveling in Y is begun. This is performed as follows:

1. Determine the elevations of the selected points by reference to some source of control data; in this case, the Geological Survey 1:24,000 scale 7-1/2 minute topographic quadrangles were used.
2. Set the floating mark on the ground at the control point near position three.

3. Set the counter to the true elevation of that point and engage.
4. Move the tracing table to the point near position five and set the floating mark on the ground.
5. Read the elevation counter and take the average of its reading and the true elevation of this control point. Set the platen to this elevation.
6. Using the tilt screws of both projectors, roll the model to bring the spot back on the ground without changing the platen elevation. The tilt screws must be moved exactly the same amount; this may be ensured by noting any Y parallax after the spot is back on the ground and removing this using the tilt screw only of one of the projectors.
7. Repeat steps two through six until satisfied with the level solution.

Once the model is leveled in the Y direction, it may be leveled in the X direction. This is done as follows:

1. Set the floating mark on the ground at the control point near position three, making certain that the counter reads the true elevation.
2. Move to the control point near position four and read its elevation.
3. Subtract the true elevation from the model elevation algebraically. Divide the result by two, and subtract this result from the true elevation, again algebraically. Set the platen to this elevation.

4. Using the single leveling screw at the left end of the frame (Number 16, Figure 4), bring the model up or down to the platen.
5. Repeat steps one through five until satisfied with the solution.

This same procedure is used for both the first and second levelings, but the first leveling need not be too accurate; within a few feet will suffice. The second leveling should be performed as accurately as possible, particularly if contours or spot elevations are desired. The control point at position six is used to check for errors in the elevation readings, recording elevations, or blunders in the field. It can also serve as an extremely sensitive indicator of small amounts of Y parallax caused by flaws in the tilt or swing orientations of one projector or the other. A point may be obtained at position seven; this serves as another check, and also indicates the magnitude of distortions in the model caused by tip errors or by radial distortions in the photography which are not corrected by the cams, if they are used.

The other half of the absolute orientation is scaling. As was mentioned in the previous chapter, the final model scale is equal to the ratio between the distance between the lenses of the projectors and the distance between the exposure stations of the original photography. Therefore the scale of the model may be adjusted by adjusting the distance between the lenses of the projectors.

Two methods of scaling were used in this research; they differ in that one used control points at the model scale and the other set the control points to the final map scale and used the pantograph to enlarge them to the model scale. The basic method, however, was the same.

The first step is to select two control points, preferably diagonally opposite in the model. A third point may be selected in one of the other corners as a check. The next step is either to determine the distance between these points or to determine their positions on some grid system, such as the state plane coordinate system. These points are then plotted. If this is done at the model scale, the result is termed a control sheet; otherwise they are part of the base map. The tracing table is then moved so that it is over one point on the control sheet or so that the pantograph pencil is over the point on the base map. Both the sheet or map and the tracing table are then moved so that the flying spot is under the same point on the model. Holding the map or sheet steady, the tracing table is moved to the other control point. The displacement between where this point is and where it should be is noted, and the projectors moved to correct about half of the distance. These steps are then repeated until the operator is satisfied with the scaling. The third point is used as a convenient check for the accuracy of plotting the control sheet or base map and also for accuracy of the identification of the control points on the model.

Interpretation

Seven different methods and combinations of source materials were used in interpreting and identifying the landform-parent material groups and engineering soil types. They may be briefly listed as follows:

1. Stereo Model: The first system of interpretation used only the anaglyphic stereo model as viewed on the platen for interpretation and identification.

2. Model Assisted by Small-Scale Contact Prints: The second system involved some interpretation on the model and some on the small-scale contact prints, viewed either in stereo or individually. The mapping was performed on the plotter, after identification on the prints.
3. Small-Scale Prints Assisted by Large-Scale Prints: The third system involved interpretation using a combination of small-scale prints and the large-scale prints. In this case the desired detail was transferred by image matching to the model and then drawn. No interpretation was attempted on the model.
4. Small-Scale Prints Alone: The interpretation was done on the small-scale prints, and the detail transferred to the map by the plotter.
5. Large-Scale Alone: The interpretation was performed on the large-scale prints, and the results transferred by detail mapping on the anaglyph model to the map.
6. Small-Scale Prints, the Model, and Agricultural Soil Survey Maps: The sixth method involved the use of the Agricultural Soil Survey Maps to assist in the location and identification of soil divisions, which were noted in some cases on the small-scale prints and in some cases on the model.
7. Small-Scale Prints, the Model, and Topographic Maps: In this last variation, the Geological Survey 1:24,000 scale 7-1/2 minute series topographic quadrangles were used in addition to the small-scale prints and the model. They were used chiefly to augment the perception of relief.

DISCUSSION OF RESULTS

Compilation

The compilation of boundaries or cultural features onto a base map by means of photogrammetric plotters is a fairly well established procedure. It was found in this case that the actual compilation was fairly straightforward. The presence of the pantograph neither made the job more difficult nor easier as far as the actual compilation is concerned. The benefits of having the first manuscript at the final mapping scale should be obvious, particularly in relation to judging the density of mapped detail. The pantograph also eliminates the reduction step which otherwise would be necessary. Furthermore, it permits placing the entire map on one sheet, rather than requiring one sheet for each model.

Several variations were tried in the orientation steps prior to the actual drafting procedure, however.

Comparison of Relative Orientation Procedures

The two variations in the relative orientation procedure were the swing-swing method and the modified rationalization method. It was observed that the swing-swing method took the author about 15 minutes for most of the models, but that the rationalization method took only about 10 minutes.

In studying the remaining parallax in models oriented by the two systems, it was found that they both resulted in a model which was

substantially free of Y parallax. It is possible that the swing-swing method resulted in slightly more tilt error remaining in the model, whereas the rationalization method tended to leave more tip error. The difference was very difficult to detect, and when residual parallax was found, it could be removed easily by either method.

In view of the time difference involved, which does not appear great but which would amount to several hours over a large project, it is recommended that the rationalization method be used for compilation of small scale photography. The conclusion is reinforced by the finding that the photography exhibited greater variability in tilt than it did in tip, and it is believed that the rationalization method does a better job of removing tilt than the swing-swing method.

Comparison of Absolute Orientation Procedures

Leveling. During the leveling phase of the absolute orientation of the models, several interesting results were noted.

The glass diapositives for this project were printed emulsion to emulsion. For this reason, it was necessary to place them in the plateholders emulsion side up. Since no correction cam was available for 0.250 inch thick diapositive placed in the plateholder emulsion side up, the cam mechanism of the plotter was disconnected. Thus, the large amount of positive radial distortion in the model, due to the refraction of light in the thick glass, was not corrected. When a model was leveled using points in the four corners and a point was read near the center of the area, it was found that the elevation of this point was in error by about 15 feet. Most of this difference was due to radial distortion.

A small component of the error was the three foot bulge in the center, due to the curvature of the earth. In most uses of photogrammetric plotters the area covered by an individual model is small enough that this curvature may be neglected, but in this case the diagonals of the model measured about ten miles long, and there is an appreciable amount of curvature in this distance. It might be necessary in some cases to take this bulge into consideration. This distortion of the model was of no consequence in this project, as neither elevations nor contours were needed.

It was further found in the leveling process that the minimum repeatability of an elevation reading was about five feet. It was noted that a movement of the platen of about five feet at the model scale was the minimum which could be noted. Furthermore, it was found that when the floating mark was lowered to the ground the elevation which was finally recorded was slightly lower than the elevation decided on when the model was approached from beneath. This difference amounted to about five feet. It was thought that this might be due to a color perception variation in the author's eyes, but it was found that interchanging the colored lenses of the glasses made no difference. This indicates that for maximum consistency, the model should be approached in the same direction every time an elevation is to be read; which direction is chosen depends entirely on the preference of the operator. It may therefore be concluded that an elevation reading, if corrected for bulges in the model, should be considered reliable to within plus or minus five feet, on this type of plotter with this type of photography. This is consistent with previously noted results (5).

Scaling. It was found that no major problems were encountered in scaling the model using a control sheet with the locations of four points marked. No difficulty was experienced in locating the selected points on the model, nor was any difficulty found in scaling the model with the standard techniques outlined previously. However, it was discovered that it was difficult to adjust the pantograph to the required reduction, as the reduction ratio between the 1:14,000 scale used for plotting the control sheet and the 1:63,360 scale desired in the final map is not an integral number. In fact, it is not even expressible in a finite number of decimal places. The difficulties involved in setting such a number on the pantograph's verniers have already been mentioned in a previous chapter. The alternate choice of using the nearest readable number was not found to be truly satisfactory, as the detail reduced by the pantograph did not fit the base. It was therefore decided that if a control sheet were to be used, some other means of reduction should be found. However, there existed an alternate method, which was to plot the control to the finally desired scale, and use the pantograph to enlarge it. Since the base maps already existed, they were used.

A certain amount of difficulty was noted immediately in this method. It was noted in the procedure outlined for scaling that the marking point of the pantograph should be set over the control point and the tracing table and the map moved together to the point on the model. Due to the great enlargement, this was found to require quite a bit of coordination. It could be done, however, and the situation improved with practice.

The base map which was used for control showed only section corners and lines and major roads. Unfortunately, the secondary road net was

desired for control. It was found that these roads are not necessarily on section lines, but are frequently found on half or quarter section lines. Road intersections, in general, had to be abandoned as a source of control and field corners used instead. This was not entirely satisfactory, as some difficulty was experienced in determining which field corner was also a section corner. Continuous reference to the 1:24,000 scale topographic quadrangles relieved this problem to a certain extent, but a certain amount of uncertainty remained which could only be resolved by using three of four section corners in each position rather than just one. This procedure worked, but slowed the process down somewhat.

A third difficulty was soon discovered. This was that a model could be satisfactorily scaled along any one line, but would often show sizable errors in the locations of other points. These errors amounted to as much as 0.1 inches on the base map. At first it was believed that this was due to inaccuracies and slack in the pantograph, and accordingly it was checked according to the previously outlined procedure. The check failed to reveal any problems. It next was suspected that the relative orientation of the model was at fault, however, this checked when performed with the utmost care. In addition, the model could be leveled at four points, which is a fairly reliable indicator of an accurate relative orientation. The next possibility was that the trouble was due to the use of the polyconic projection for the base. Calculations showed, however, that although this could contribute a small amount of scale error, it could not account for errors of the amount which were being encountered. This left the plotting of the base map as the only source of error left, and a few random checks of this plotting against the coordinates on the

1:24,000 scale topographic quadrangles, which are fairly reliable, indicated that, in fact, errors of the magnitude found did exist in the relative locations of section corners. It is not known whether these errors also exist in the drainage maps from which the base maps were traced, but it is believed that they may. Whatever the source of these discrepancies, they did exist and a way had to be found to overcome them. This was eventually done by scaling the models in areas of about 36 square miles at a time, instead of attempting to scale the entire model at a time. This procedure was slow, but it solved the problem.

It is recommended that in future compilations a slightly different system of control be used. This is to select control points, such as road intersections, which are easily noted on the photography. The next step would be to obtain their coordinates from the 1:24,000 scale topographic quadrangles, much as would be done if a control sheet were to be plotted. Instead of plotting the points' coordinates to the model scale, however, they could then be plotted to the final map scale. This procedure is termed a point base, and the model can be controlled using this point base instead of the precompiled base maps which were used on this project. All the necessary detail, except the section lines of course, can then be plotted using the photogrammetric plotter and a precompiled base becomes unnecessary. This approach was not tested, as a way could be found to make the base maps work, as was noted.

The conclusion which may be reached in spite of all the difficulties mentioned above is that compilation of reliable soils maps is possible using this type of plotter and the small scale photography in the form of diapositives. This is because although the difficulties did make the

compilation more difficult, they did not make it in any case impossible, and the results were quite reliable.

Interpretation

Seven different systems of interpreting and identifying the engineering soils groups and the landform-parent material types were tried in this research. These seven were briefly described in the previous chapter. None of these systems was a total failure, although one of them did not seem to belong and another was not generally useful. It was found that not all of the systems could be used everywhere in the area, nor for every purpose.

Before discussing the results of the research system by system, it would be good to refer back to Figure 3. The relative areas which may be seen on the small scale prints, the large scale prints, and the viewing platen of the plotter have some bearing on the results, as will be shown.

Comparison of Interpretation Procedures

Model Alone. The first of the seven methods was to perform all of the interpretation on the platen alone, that is, at the model scale. Of the seven, this is possibly the simplest and the most desirable system. Also, of all the systems, this was the one which worked the poorest. No problems developed in identifying and delineating the broundaries of small features, such as individual muck pockets or small sand dunes. However, it was soon found that the identification of overall features, such as a ground moraine or an outwash plain, was nearly impossible. This is believed to be due to the fact that these types of terrain are interpreted in large part by their overall patterns, with relatively little attention

being paid to the actual nature of the elements making up those patterns. The elements of the pattern, such as muck pockets, channel scars, and the like, were clearly visible on the platen. These forms frequently were of such a size that one element occupied most of the field of view, or even all of it in the case of a large muck pocket. Since this was all that could be seen at one time, it was extremely difficult to obtain any over-all idea of the pattern which these elements formed. It was found that it was nearly impossible to distinguish between an outwash plain and a ground moraine, or between a terrace and some areas of ground moraine, particularly when the latter was covered with silt. It was also found that while certain boundaries were easily followed, most were not. The difficulty of following a boundary did not have much to do with the nature of what was on either side, but was rather dependent on the nature of the break itself.

Certain boundaries were found to be very sharp, definite changes. An example would be the break between an upland plain and a terrace; the valley wall is fairly obvious because of the large topographic difference. Other boundaries are obvious because of a marked change in material charater; an example of this type is the boundary between the ground moraine and the sand dunes. This type of boundary could be followed and delineated without difficulty on the model, since there was never a break in the line which exceeded the diameter of the platen. Some of the other boundaries were of a gradational nature. That is to say, there was no sharp line of demarcation to be found. This type of boundary is in the majority in soils mapping. On one side of a certain zone a positive identification of some type could be made, and on the other side an equally

positive identification existed. But there would be an area in between, a transition zone, which exhibited the characteristics of both. This type of boundary proved to be, for all intents and purposes, impossible to follow using just the platen alone. In some areas the zone would be narrow enough to be encompassed on the platen, but in most areas this was not so. As a result of this difficulty, interpretation of the small field of view on the platen is not recommended for general use.

Model Assisted by Small Scale Contact Prints. The second method tried was to do some interpretation on the model, but to do the majority of it on the prints of the small scale photography. This turned out to be quite successful. The smaller areas, such as muck pockets, were easily delineated on the model, as was mentioned above. It was found that the small scale prints, covering as they do almost 100 square miles, made both the identification and delineation of most of the regional areas very easy. The scale in this case was such that the boundaries which gave so much trouble in the first case appeared to be almost as narrow as lines. As such, they were quite sharply defined and easily drawn. Also, since the regional patterns were visible in one sweep, identification of the materials on either side of the boundary was fairly easy. In certain cases it was found that a positive identification with regard to particle size could not be made, however. In these respects it was much like identification on mosaics of the more familiar large scale photography, with the psychological benefit of stereo. This method was very successful in most situations. However, it was found that the minimum amount of local relief which was observable and could be accurately judged was about 20 feet. To judge the relief of a rolling

surface with a local relief of less than that, it was necessary to take systematic spot elevations. Even the 20 foot minimum value was only noted if the interpreter had a good idea that such relief could be expected; otherwise it was difficult to judge less than about 30 feet of local relief. This meant that certain landforms were very difficult to delineate or identify. This was particularly true of some low terraces along the Wabash River near Delphi, and it was also true of some very low possible ridge moraine areas. It was not possible to decide whether these areas were indeed ridge moraine without ground study or some other means of control. In other counties this might not be a limitation; however, it was a serious problem in this area.

Small Scale Prints Assisted by Large Scale Prints. The next method tried was to interpret and identify the landform-parent material groups using the small scale prints and the large scale prints. In this case it was found that although the smaller areas could be found, using magnification, on the small scale prints, they were more easily found on the large scale prints. The boundaries for the larger areas were best found on the small scale prints, with their regional view of things, as in the previous case. This third method eliminated the problem encountered in the second method with respect to topography, as the amount of local relief could be judged on the large scale prints. However, a completely unexpected problem eliminated this method quite completely from consideration, along with the fifth method listed. This problem was the difficulty encountered in correlating detail on the large scale prints with either the smal scale prints or the platen. This was due partly to scale considerations, but mostly to changes in farming. In the areas where the formats had not changed their

plowing schemes or their woodlots, or in areas which were not farmed, very little difficulty was experienced in correlating the desired details. In those areas which were heavily farmed, however, which make up the majority of the area, the 13 year time span between the two coverages meant sizable differences in the locations of almost any identifiable, unambiguous details. This caused considerable difficulty in transferring the details of the boundaries. Consequently this method was abandoned in hopes of finding something better.

Large Scale Alone. The fifth method, to take it out of order, was to use the large scale prints alone. This abandoned the regional view advantage of the small scale prints, and incorporated all the problems of the large scale prints noted under the third method. All that can honestly be said for this method was that it worked better than the first method. It was much slower and more tedicus, however, due to the large number of photos involved. The author believes that using only the large scale photography for interpretation, confining the small scale photography to mapping, is at best a very slight improvement over the present system of compiling the maps in areas where the agricultural soil survey maps are not available. This method was discarded after a relatively short test.

Small Scale Prints Alone. The fourth method was to perform all the interpretation and delineation on the small scale prints alone. This proved to be feasible, particularly if the prints were viewed with magnification. However, it offered no improvement over the second method in regard to the delineation of areas marked off by differences in local relief, as might be expected. In addition, it was somewhat slower, as

it was necessary to mark out all of the muck pockets twice. It was found in addition that some of the smaller muck pockets were overlooked on the prints, and were only noted in passing on the model. Thus, it was felt that this method offered little improvement over the second scheme. The improvement which did exist was that the individual who was operating the plotter did not need to be able to interpret, but could simply follow the boundaries marked on the prints for him. This could be an advantage to be noted in certain situations, but was not important in this project where the interpreter and the compiler were one and the same.

Small Scale Prints, the Model, and Agricultural Soil Survey Maps. The sixth scheme tested involved use of the small scale prints, the model, and the agricultural soil survey maps together. This method enabled the delineation of all but the suspected ridge moraine areas. It did improve matters over method number two in one important respect. This was because it was possible using the agricultural soil survey maps to identify the materials in certain areas which had been noted on the prints, but which could not be positively identified. These turned out to be areas of either ground moraine or outwash plain with a very thin overlay of loess. Since the agricultural soil was in a different catena in these areas, it was easy to note them on the soil survey maps and then to determine what they were. It should be noted that the boundaries visible on the photography agreed well with those shown on the soil survey maps, indicating the ability to note a difference in material type with the small scale prints, even if it is impossible to say what it is. This sixth method worked very well. It did, however, have two main disadvantages. The first was that it still did not enable differentiation

between rolling ground moraine and low ridge moraines. The second was that it is limited by the fact that not all the counties in the state are mapped at this time, and some of them were mapped too long ago. White County in the project area, mapped in 1915, fell into the latter class. It was found that the soil survey map of this county was virtually useless. Having the soil survey map of Carroll County did eliminate the necessity of visiting some of the sites, however, and for that reason it is recommended that the soil survey maps be a part of the mapping project wherever recent ones are available.

Small Scale Prints, the Model, and Topographic Maps. The last method tried was to use the small scale prints, the model, and the 1:24,000 scale 7-1/2 minute topographic quadrangles in conjunction. It was found that this method was very powerful. The interpretation of most areas could be done as mentioned in the discussion of the second method. In areas where the amount of local relief was questionable, the topographic quadrangles, which in this area have contour intervals of either five feet or ten feet, could be used to judge the topographic forms. The procedure operated very efficiently, and resulted in the positive identification of some areas in southern Carroll County, which had been thought of as possible ridge moraines, as rolling ground moraines. These topographic maps also made possible the discovery of some low terraces along the Wabash River. The problem of identifying the materials in a certain few areas still remained, however, and could only be removed by referring to the agricultural soil survey maps or by field investigation.

Summary. In summary, three methods were tried in which only one source of information was available to the interpreter. In this area,

all three of these methods ran into situations in which they did not perform well, although only one of them ran into a situation where it was totally useless. The systems which showed promise were the ones which used two or more sources of information. In general, it was found that the more sources used, the easier and more certain were the identifications which could be made. It was decided that since the topographic maps were already available for control purposes, the information contributed by the large scale photography was to be found either on the small scale prints, the model, or on the topographic quadrangles. They were therefore somewhat redundant. In addition, the sheer volume of work which their use entails defeats whatever slight increase they might bring. Since the results were felt to be as reliable without them as with them, the author believes that large scale photography is not necessary to these procedures.

Analysis of Photointerpretation Procedures

It was observed that there seemed to be two distinct phases to the photointerpretation problem. The two phases are identification of the material present in any given area, and the determination of the boundaries of that material. The problems presented by these two phases of interpretation were found to be quite unrelated. In both cases, however, small scale photography was found to be a help rather than a hindrance.

Material Identification. The problem of the identification of a material breaks down into first identifying the landform and parent material found in the area, and determining the general particle size and grain of the soil. It was found in this research that the positive

identification of the landform and parent material in any given area was generally easier on the small scale photography than it was on the large scale coverage. The exception to this, of course, was differentiation between ridge moraines and rolling ground moraines. It was found that the convenience of being able to observe an area of about 100 square miles in one view, and then being able to "zoom in" on one particular area by using a magnifying glass was not to be disregarded. It was found that viewing the large area helped greatly to fit each of the individual features into place. In those instances when fine detail, such as gullies, had to be seen to aid in the identification of particle size, it was found that these details could be seen on the prints, using magnification. The resolution of the photography was high enough that they were not lost. How much smaller the scale could be made and still be able to see such detail is not known, but it was found that as far as resolution is a criterion, the scale of this photography is not the limit. There was only one instance, landforms defined solely on the basis of local relief, that it was not possible to make a certain identification on the small scale photography. With the given focal length, that is to say, limited to the available photography, the only solution to this problem is either to use a more sophisticated, first order, plotter/comparator, or to use some form of supplementary information. The topographic quadrangles are to be preferred both because of the ease of correlation and the fact that they are used elsewhere in the mapping sequence.

Delineation of Soil Boundaries. The problem of determining the extent of a soil once it is identified is not related to the problem of identifying the soil. In the case of the boundaries, the nature of the

materials on either side of the boundary were not found to make too much difference in the ease or difficulty with which a boundary could be followed. The critical factor was the nature of the boundary itself. It was found that boundaries could be divided into four classes: the first contains those which are continuous and are closed in a small area, perhaps one square mile or less. The second group includes those which are continuous, but extend over large distances and are either large topographic breaks or sharp pattern changes or both. The third group encompasses boundaries which are formed by very small topographic breaks, but are again of large extent, such as the boundary between two terraces. The last class of boundary is unfortunately the most common one. This is the class of boundaries which are rather diffuse, and which can better be described as transition zones rather than sharp lines of demarcation. The best example of this class would be the boundary between a loess-covered ground moraine and a ground moraine; the silt thins so gradually that the boundary zone may be several miles wide.

It was observed that for the first type of boundary delineation was best accomplished on the platen, at model scale. These boundaries are small enough that they either close or nearly close on the platen, and thus they may be easily followed. They were so small that marking them on the prints was found to be somewhat frustrating. The second class of boundary could be easily followed on either the prints or the model. Therefore, it was sketched on the prints and the details were added when it was delineated on the platen. The location of the fourth type of boundary was best determined on the small scale prints, and it was found that the best system for mapping these was to mark the boundary with care

on the prints, and then to transfer it to the model by careful image matching.

The third class of boundary could only be found on the photography by taking very careful, repeated spot elevations in systematic traverses. The author found that once he was aware of the location of this type of boundary, he was generally able to follow it adequately on the platen. This type of boundary could be found by very careful profiling if it were necessary to operate solely from the small scale photography. It was found that this sort of boundary showed up well and could be followed best on the topographic quadrangles.

Anaglyphic Projection System

Intensity. It was found in all cases of interpretation on the model that the light balance between the two projectors should be quite even. The author noted that the apparent tone contrast was badly distorted if either projector was much brighter than the other; that is to say, if there was a pronounced red or green cast to the image. A Weston Master III light meter was used to verify that the tone contrast was in fact the same no matter what the balance of the projectors was; it thus appears that this is a psychological effect. It was found that occasionally it was possible to misinterpret the degree of organic content in the soil because of this distortion. The rheostats should be carefully adjusted to ensure an image which appears to be a neutral grey. The author has found that certain other projectors provide lighting which is as bright, but much more even than the type of machine used.

It was observed that the intensity of the floating mark was somewhat critical when reading elevations. If the spot was too bright, it appeared to spread laterally and the reliability of the elevation readings suffered. The floating mark should be turned down to the lowest level at which it may be easily seen.

Field of View. It was noted that considerable difficulty was found in interpreting the landforms on the model. This was not due to the scale of the model, but was due to the very small area of the model which could be viewed at any one time. Certain other types of double projection plotters enable viewing the entire model area in stereo by illuminating the whole diapositive. This is accomplished at no appreciable loss of resolution (5). The author feels that all of the interpretation could be performed on such a plotter which could be performed in this research on either the model or the small scale prints. He also believes that it would be easier than working on either the model used in this project or on the small scale prints. Furthermore, the use of the other type of plotter has been noted to speed up the relative orientation process somewhat. It is therefore recommended that the other type of plotter be investigated.

Cost and Time Comparisons

It is somewhat difficult to assemble cost figures for comparison purposes, but it is believed that the system described in this thesis is somewhat cheaper. It is noted that the glass diapositives for this plotter cost $5.00 apiece in quantities of less than 100 but more than six, or $4.50 apiece in greater quantities. It is suspected that for

an average county, approximately 20 diapositives would be required. Assuming that several counties would be ordered at once, this would cost $90.00 per county. Since contact prints were found useful, these too should be ordered, at a cost of $0.65 each or about $13.00 for each county. Thus the cost of acquiring small scale coverage would average just over $100 per county, again assuming that several counties are acquired at the same time.

Time is also a significant factor in cost comparisons. It was found that the time required for compilation averaged about one hour per model, depending somewhat on the complexity of the area. The time required for interpretation using the recommended system varied over a much wider range, but probably averaged about two hours per model. It was found that it took approximately the same time to interpret a large scale model as it did to interpret a small scale one, in spite of the difference in area covered.

For the time comparison, it is estimated that 100 to 200 man-hours would be required to interpret and compile the average county using the small scale photography in the photogrammtric plotter, in sharp contrast to the estimate of 600 to 1300 man-hours which would be required for interpretation alone in a county mapped using the large scale photographs.

These cost and time figures, of course, assume that the person performing the work has had prior experience in operating the plotter. On the other hand, they do not include the time and cost induced by having to transfer the detail found on the large scale prints to the 1:63,360 base maps. This step is automatically included in the figures for the system described in this thesis.

The Product

Two maps were prepared as a part of this project. One was made of Carroll County and one of White County. They served as experiments and also as data to check the accuracy of the results.

It was chosen to check the soils shown in Carroll County against the soil groups shown on the Agricultural Soils Survey Maps of this county. The check was performed simply by noting the relative positions of boundaries delineated on the engineering soils map and the boundaries found on the Agricultural Soils Survey Maps. It was noted in cross-checking the boundaries that they coincided very closely in the case of those with some type of sharp break. The coincidence was not as sharp, although still excellent, in the case of boundaries such as would be found between an outwash plain and a ground moraine. The boundaries between the silt covered ground moraine (or outwash plain) and the other areas had been originally determined with the aid of these maps, and thus they could not form a valid check. In general it may be said that, inasmuch as could be conveniently checked, the boundaries delineated in the course of the experiments agreed very well with those shown on the agricultural map. No effort was made in this county to check the accuracy of the determination of texture classes, as these were taken originally from the check maps. In the course of a field examination, however, no sizable departure from the estimates on the maps were noted.

In White County, it was found that the Agricultural Soils Survey Map was so old that it was not particularly useful for anything. A field study of the area was undertaken partly to determine material sizes and partly to check the accuracy of the boundaries delineated. It was

found that in general the boundaries as determined in the field agreed well with what the map stated. Again, the agreement was excellent in the case of those boundaries which were sharply delineated, and not as good for the more gradational boundaries. It should be noted, of course, that it is really impossible to state that any given line, either on the ground or on the photograph or on the map, is the boundary in these gradational cases. It was also found that the material size estimates made while delineating the boundaries on the photography agreed fairly well with the ground truth.

In checking the two maps produced in this project with the ones available for the adjoining counties, it was found that in several cases there were differences across the county lines. In these cases the data produced in the project was first double checked on the photography, and then checked in the field. It was found that in most of these cases either interpretation appeared to be equally valid, due to a gradational situation. In one instance an area of sand dunes had been indicated on a previous map, however, the author was unable to find the dunes on a visit to the area. It is felt that they had been removed at some previous time for construction. It was found that the check across the overlap areas was at least as good in the case of these two maps as it was with any other boundary line on any other pair of maps.

It was finally concluded that in spite of the rapidity of the process it was capable of producing maps which were the equal of the maps in the adjacent areas.

CONCLUSIONS

Two conclusions may be drawn from the research conducted under this project.

1. Except in cases where the boundary between two engineering soil groups is determined by a relief difference of less than about 20 feet, the small scale photography as used in this project may be used for the interpretation and delineation of engineering soils groups, either viewing it directly or using enlargement.
2. Compilation of the boundaries of engineering soils groups on maps at a scale of about 1:63,360 can be readily and reliably accomplished using small-scale photography in double projection plotters supplemented by certain subsidiary materials for control and the determination of fine relief differences. This compilation is as reliable as that performed by other methods, and may be accomplished at a considerable savings of time and money.

RECOMMENDATIONS

On the basis of this research, it is recommended that the following supplemental method be used in the compilation of the preliminary engineering soils maps on a county basis:

1. The interpretation and delineation of the engineering soils groups should be accomplished on the small scale photography. This may be done for certain groups on paper prints, and on others on the plotter. The agricultural soil surveys should be used to augment the procedure where they are available, and likewise the 1:24,000 scale 7-1/2 minute series of topographic quadrangles should be used to augment the perception of fine relief differences.
2. The maps themselves should be compiled in a double projection plotter, similar to the type used, using the small scale photography in the form of glass diapositives printed for projection emulsion down.
3. The relative orientation of the models should be performed using the rationalization method, if the operator is familiar with the method.
4. Horizontal control for these compilations should be in the form of a point base at the final map scale. It should be chosen using the photography to find easily identified points, and the coordinates should be obtained from the 1:24,000 scale topographic quadrangles.

5. Vertical control should be obtained from the topographic quadrangles, and is most convenient in the form of elevation data for the same points as are used for horizontal control.

Further Research

The author sees some value in certain avenues of further research on the general subject of the adaption of small scale photography to engineering soils mapping. Specifically, he would recommend:

1. That a similar project to this one be undertaken in an area where the soils are residual on rock, such as may be found in portions of southern Indiana. It is believed that in such areas small scale photography may not need the support of topographic information for interpretation and identification.
2. That a study be undertaken to determine the value of using color photography at small scales. It is recognized that the addition of color to the differences visible on photography aids in the interpretive process (2), and it is possible that the benefit would be great enough at the small scales to justify the additional expense.
3. That a study be undertaken of the use of super wide angle photography at these scales. One of the problems noted in the research was the inability to determine small amounts of local relief on the model formed by the small scale photography. This is due to the fact that from the altitudes necessary to fly this photography with a six inch lens, small relief differences generate such small amounts of differential parallax

that they become imperceptible on this type of equipment. However, the super wide angle photography using three inch lenses produces the same area of coverage at the same scale at half the altitude. Consequently, since differential parallax is a function only of the height of the object and the flying height of the aircraft, it is roughly twice what it would be for a given object on the six inch focal length photography. Or conversely, an object only half as high can be reliably measured on this type of photography. However, there are certain disadvantages which come with this benefit. Chief among these is that slopes greater than about 30 degrees will not have stereo coverage. This is due to the very low grazing angle of the rays from the ground to the lens at the limits of coverage. Whether the loss of relief detail on these slopes is too great a penalty to pay would have to be studied. It should further be noted that super wide angle photography is not yet available on a general basis, and the cost of the special photography might be excessive.

4. That a study be undertaken using the small scale photography used in this project in a double projection plotter similar to the Balplex. In this type of plotter, it is possible to view the entire model area in stereo at once, instead of the rather small area of the platen. It is felt that this might be an advantage, and might eliminate the necessity of having to refer to prints of the coverage. Furthermore, these plotters permit the orientation simultaneously of several models, permitting the viewing of an even wider area.

Pending these researches, however, the system followed in this thesis is believed to be entirely adequate and is recommended.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. *Manual of Photogrammetry*, American Society of Photogrammetry, Washington, 1966.

2. *Manual of Photographic Interpretation*, American Society of Photogrammetry, Washington, 1960.

3. Miller, Victor C., *Photogeology*, McGraw-Hill Book Co., Inc., New York, 1961.

4. Ray, Richard G., *Aerial Photographs in Geologic Interpretation and Mapping*, Geological Survey Professional Paper 373, United States Geological Survey, Washington, 1960.

5. __________, "Photogeologic Procedures in Geologic Interpretation and Mapping," Geological Survey Bulletin 1043-A, United States Geological Survey, Washington, 1956.

General References

1. Davis, M. M., *Engineering Evaluation of Northwestern Indiana Moraine, Lacustrine, and Sand Dune Airphoto Patterns*, (Thesis), Lafayette, 1949.

2. Fenneman, N. M., *Physiography of Eastern United States*, McGraw-Hill Book Co., Inc., New York, 1938.

3. Hemphill, Wm. R., "Determination of Quantitative Geologic Data with Stereometer Type Instruments," Geological Survey Bulletin 1043-C, United States Geological Survey, Washington, 1958.

4. __________, "Small-Scale Photographs in Photogeologic Interpretation," Photogrammetric Engineering, Volume 24, No. 4, p. 562-7.

5. Johnson, A. M., *Airphoto Interpretation and Engineering Evaluation of Northwest Indiana Sands*, (Thesis), Lafayette, 1949.

6. Montano, P. A., *The Engineering Significance of Airphoto Patterns of Northern Indiana Soils*, (Thesis), Lafayette, 1946.

7. Pillmore, C. L., "Application of High-Order Stereoscopic Plotting Instruments to Photogeologic Studies," Geological Survey Bulletin 1043-D, United States Geological Survey, Washington, 1957.

8. Ray, Richard G., "Scale and Instrument Relationship in Photogeologic Study," Photogrammetric Engineering, Volume 24, No. 4, p. 577.

9. Scher, M. B. and Thompson, M. M., "Kelsh Plotter Procedure," United States Geological Survey Circular 357, United States Geological Survey, Washington, 1954.

10. Thornbury, Wm. D., Principles of Geomorphology, John Wiley & Sons, Inc., New York, 1954.

11. Woods, K. B. et alia, Highway Engineering Handbook, McGraw-Hill Book Co., Inc., New York, 1960.

APPENDIX A

APPENDIX A

THE AIRPHOTO INTERPRETATION OF ENGINEERING SOILS OF CARROLL COUNTY, INDIANA

Introduction

The engineering soils map of Carroll County, for preliminary engineering purposes, was prepared as a part of the research discussed in the thesis of James C. Hall, published in January, 1967, and entitled Preliminary Engineering Soils Maps from Small Scale Aerial Photography. The purpose of this report is to supplement the map, providing miscellaneous information which could not be placed on the map.

The original map manuscript was prepared as part of an experimental mapping project making use of 1:69,000 scale aerial photography flown originally for the United States Army Map Service. This photography was used for the interpretation and identification of the engineering landform-parent material groups and engineering soils groups, for determining their boundaries, and in conjunction with a plotter for plotting the boundaries on a base map. A double projection plotter of the Kelsh type, equipped with a pantograph, was used for the map compilation and for some of the interpretation and identification.

A number of other materials were used to assist and supplement the aerial photography both in the interpretation and identification of the soils and in the preparation of the map. These other materials included

the 1:20,000 scale aerial photography available from the Department of Agriculture for additional photographic coverage. Information concerning the soils was derived in part from the Agricultural Soil Survey of Carroll County prepared by the Soil Conservation Service of the Department of Agriculture (7). The Danville map (NK 16-11) of the Army Map Service 1:250,000 scale 1° by 2° map sets was used for initial location. The 1:24,000 scale 7-1/2 minute series topographic quadrangles available from the United States Geological Survey was used for control and for interpretation in some cases.

Data concerning the particle size and texture of the materials were extracted from the Agricultural Soil Survey, supplemented by very limited field checking. These data are not intended to be considered as anything but an estimate, and as such engineering projects in this County should include detailed field exploration and testing of soils. The subdivision of soils into groups was limited to textural groups associated with landforms and parent materials, with a few exceptions. The most notable of these are the areas of loess overlying glacial drift, and the areas of muck, peat, and highly organic topsoil. An effort was made to delineate the larger examples of these soil groups.

Description of Area

General

Carroll County is located in the northwestern part of Indiana, approximately half way between Indianapolis and Chicago. The location and shape are illustrated in Figure A1. It has a total area of about 374 square miles. The total population in the 1960 census was 16,934

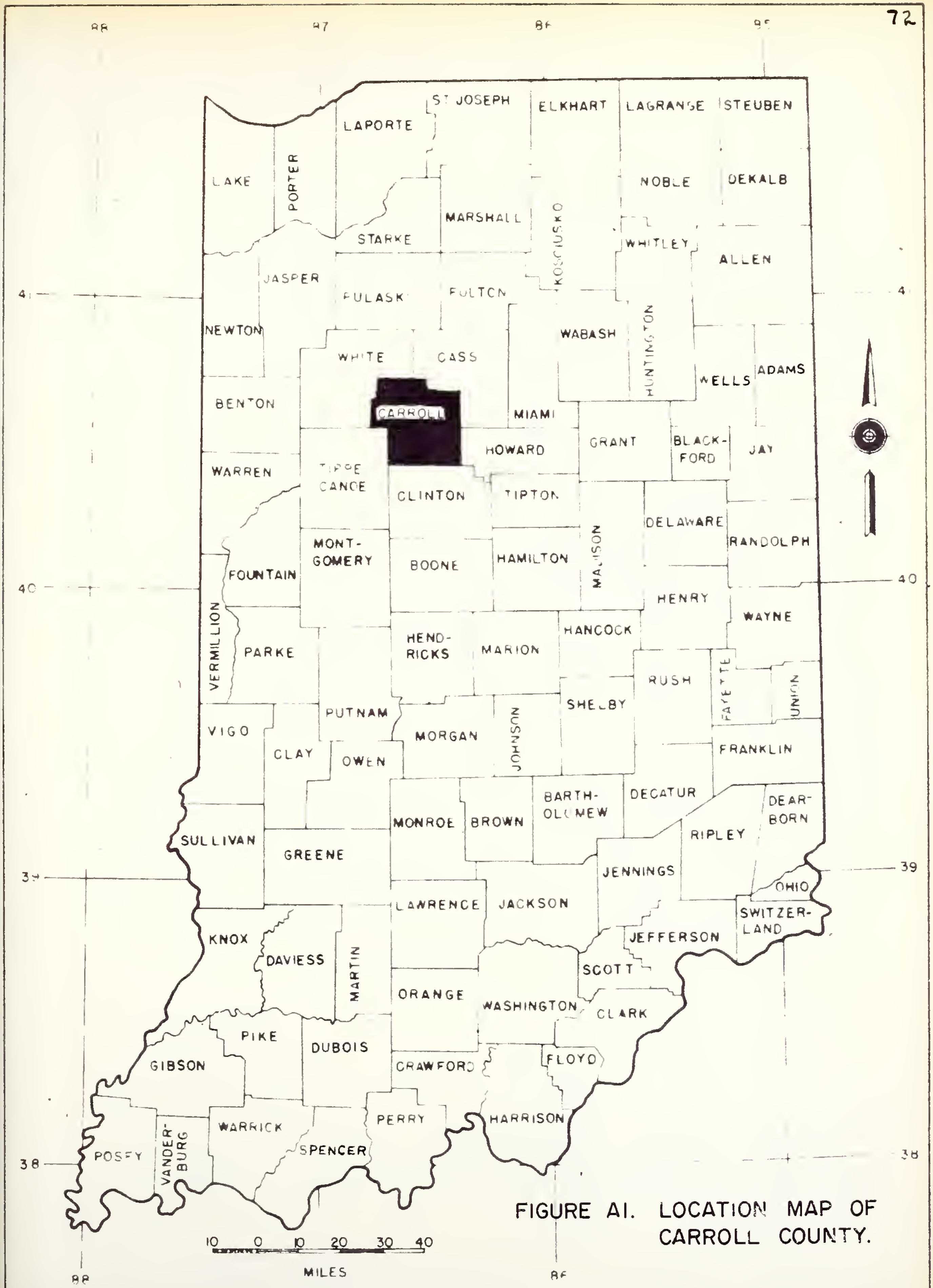


FIGURE A1. LOCATION MAP OF CARROLL COUNTY.

people. Two thousand five hundred and seventeen people lived in the county seat of Delphi, and another 1,742 lived in the town of Flors (5). The remainder of the population lives either in small centers of less than 1,000 people or on farms (5). A slight decrease in total population has occurred since 1930.

The county seat of Delphi is slightly north and west of the geographical center of the county, and is located between the Wabash River and Deer Creek. Industry is concentrated in Delphi, and includes some light manufacturing (7). However, the economy of the county is primarily farm-oriented, and the great majority of the acreage is tilled. The principle income is from livestock (7), and a sizable portion of this livestock appears to be horses and ponies.

Drainage Features

The drainage of Carroll County is dominated by the Wabash River, which flows across the county from northeast to southwest. It occupies a fairly deep valley which was cut principally by floods from glacial Lake Maumee, which existed in the present Lake Erie basin for a time at the close of the Pleistocene (3). The only other major stream is the Tippecanoe River, which forms a portion of the western boundary of the county. The remainder of the drainage consists of small streams. South of the Wabash River, the streams flow in a generally westward direction, and north of the river they flow in a generally southward direction. These small streams are consequent on the ground moraines. Some evidence of control was noted on the photography for two of them Rock Creek and Deer Creek, and a subsequent field trip confirmed that these two streams

have cut down to limestone rock near the points where they enter the valley of the Wabash River.

There are no natural lakes in this county. However, a hydroelectric power dam on the Tippecanoe River has formed Lake Freeman on the border with White County to the west. This lake provides an excellent recreation area. There are a few other artificial lakes in the county which have been constructed for flood control purposes. These are also used for recreation. In addition, there are a few small ponds in some of the depressions. Some of these may be natural, but it would appear that the majority are artificial.

Topography

The topography of Carroll County is basically the very gently rolling plain of the Wisconsin ground moraine. The plain is broken by the 50 foot deep valley of the Wabash River and by the lesser valleys of the various small tributary streams, as well as by the valley of the Tippecanoe River. Near these streams the plain is moderately dissected; however, this dissection disappears away from the streams and most of the upland is without well defined valleys. The slopes on the upland are rarely greater than about five percent. The elevation of the upland varies around 700 feet above sea level, and the lowest point in the county, on the Wabash River at the western border, is about 650 feet. The distinction of being the highest point in the county is quite meaningless, due to the smoothness of the upland. The greatest local relief on the upland occurs in the southern part of the county, where there is an area in which the relief may be as much as 15 feet. The valley walls

are in general very steep. There are at least two distinct levels of terracing found in the Wabash River valley. These terraces continue into the tributary stream valleys in some cases.

Geology

The cover of glacial drift in Carroll County ranges from none in several locations on the rock bench near Delphi to over 150 feet thick in some other places (7). The glacial drift is somewhat complex, as it is in the area where the Lake Michigan, the Lake Erie, and the Saginaw lobes of the Wisconsinan ice sheets coincided (3). However, it is believed that the last ice to leave was from the Lake Erie lobe, and that it receded about 10,000 to 15,000 years ago (3). As is common in the Wisconsinan till sheets, the materials of the drift are fine grained, being almost entirely clay in the upland areas. There is some gravel, but it is mostly widely scattered. No significant ridge moraines were found in this county.

The valley of the Wabash River was formed by meltwater as the glaciers were receding from the Lake Erie lobe (3). The valley also formed the spillway for the pro-glacial lake, called Lake Maumee, which was trapped between this lobe and the moraine systems near Fort Wayne, Indiana (3). Both in the vicinity of the valley and within the valley the surface drift consists of more or less stratified and sorted deposits which are classified as outwash plain, but which are either outwash or reworked tills. It is believed that the terrace system within the valley was formed by fluctuations in the gradient of the Wabash River due to variations in load, volume of water, or the outlet elevations downstream (3, 8).

The bedrock in this area is exposed at several locations in the vicinity of Delphi, which is built on a rock bench only thinly veneered by alluvium. The bedrock consists of either Silurian limestone or Devonian shale. The limestone outcrops in several stream valleys, and is also quarried near Delphi. The shale is thinly bedded and weathers readily. It tends to be quite soft, and no solid outcrops of it were noted, although it does form the valley walls in places. It is believed that the bedrock surface is fairly sharply rolling in a mature type of topography, much like the present land surface in the immediate vicinity of the Ohio River in southern Indiana. The bedrock topography is dominated by the valley of the Teays River, a preglacial stream which had a drainage basin extending to the Blue Ridge on the east and with a total area somewhat greater than the present Ohio River basin. This was, therefore, a fairly major stream, and it is believed that the elevation of its valley at this point was somewhat less than 500 feet above sea level (3).

The limestone, which is still actively quarried, is used mostly for agricultural lime, although some of it could be used for aggregate. It tends to be cherty.

Land Forms and Engineering Soil Areas

The soils of Carroll County may be divided into three groups. These groups are: glacial deposits, fluvial and glacio-fluvial deposits. and miscellaneous deposits. Further subdivisions of these groups will be noted as they occur.

Glacial Deposits

The glacial deposits constitute the greatest portion of the area of Carroll County. They occupy the entire area south of the Wabash River, with the exception of a few flood plains. They also occupy some of the area north of the river. Certain maps have indicated the presence of a ridge moraine in the southern part of the county, and some scattered ridge moraines in the northern part. However, these sites were visited on the ground and it was determined that they did not differ significantly from the surrounding ground moraine from an engineering standpoint. They were not, therefore, mapped as a separate unit.

Ground Moraine. The ground moraine in this area is gently rolling, with a local relief varying from a few inches to a maximum of 10 to 15 feet. In spite of this relatively low relief, the topographic position of the soil makes a considerable difference in its composition. The soils in the higher areas tend to be somewhat lower in organic content than the remainder. They are typically silty clays or silty clay loams in texture. The soils on the slopes are also relatively low in organic material, being, like the higher soils, a yellow brown color. They are also generally silty clays or silty clay loams, but are very slightly coarser than either the higher soils or the lower soils. In the low swales, which serve as drainage ways, the surface soils have fairly high organic contents. The drainage of these soils, in contrast to the previous two, may be described as poor, instead of merely fair to poor. These soils exhibit more clay than the soils in the higher position. In certain areas these low soils grade into highly organic soils or into peat or muck, which is discussed later.

The unconsolidated material underlying the topsoil is most likely composed of particles ranging in size from large gravel to the finest clays, with a predominance of the silt and clay fraction. No borings were made in connection with this project, and subsurface investigations should be conducted for any large projects. It is very doubtful that any deposits of gravel usable as construction material exist in the area marked as ground moraine.

The soils of the ground moraine are not particularly good for construction. It is anticipated that two main problems will be encountered. The first is that materials for subbase and base courses for roads would be quite difficult to find. The material in place is not believed to be suitable for such purposes. The other problem is that due to their poor drainage characteristics, consideration would have to be given to developing good drainage on any project. In some areas it was noted that field drain tiles were being used, and these would be a potential construction problem.

Fluvial and Glacio-Fluvial Deposits

Fluvial and glacio-fluvial materials appear in the Wabash River valley, adjacent to it, and along the valleys of some of the tributary streams. There is no reason to suppose that these materials are very deep. They do, however, constitute the parent materials.

Flood Plains. The alluvium in this area, found mostly in the flood plains proper, is well stratified. The materials are generally sands and some gravels, although there may be lenses of silt. The material is, however, relatively clean of the clay fraction, and organic material

is quite rare, although some may be found in occasional meander scars. It was noted in field studies that the bed of the Tippecanoe River contains sizable quantities of boulders derived from the upland tills in times of flood or high water. It is possible that in certain localities these fluvial deposits may provide sources of gravel, however these gravels are liable to be cherty. This is due to the fact that the gravels were derived either from the till which was derived from the cherty Silurian limestone and is therefore cherty, or from the cherty Silurian limestone directly. Considerable caution should be taken in using these as aggregate to avoid adverse reactions*.

The drainage on these fluvial soils tends to be quite good due to their coarse grain. However, the water table near the streams is quite high. In addition, some areas are exposed to the danger of flooding.

Outwash Plains. The areas delineated and identified as outwash plains are the result of the great torrents of water which flowed off of the front of the melting continental glaciers. They are either areas where the material was in the form of part of the load of these torrents, and was emplaced, or they are areas where the water reworked and partly sorted the already existing tills. In either case, they are not as well sorted as the fluvial materials. They tend to be somewhat high in silt, but the author noted that any one sample appeared to be quite variable in grain size. The drainage is in general fair. Surface drainage is principally in channel scars on the surface formed by the outwash floods. The landscape has slightly more relief than the ground moraine, however it was found that, particularly on the north bank of the Wabash River,

---

* Personal communication, Prof. K. B. Woods, Purdue University.

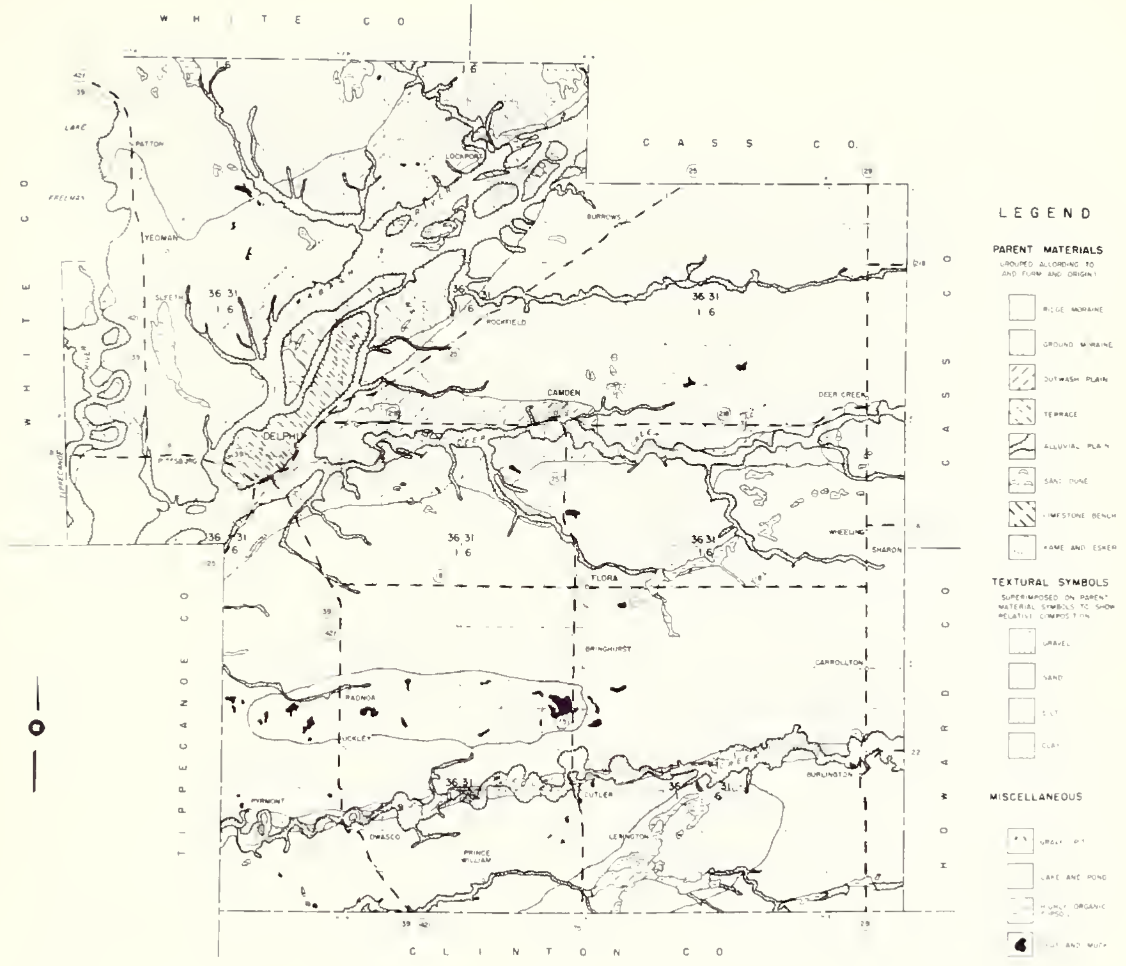
all these soils tended to be quite high in organic materials (7). The overall composition of the outwash, taken as an average, resembled the composition of the nearby tills quite closely. It is not likely that any clean gravels will be found in the area, except at depth, and in general the remarks made under ground moraine with regard to problems of construction will apply.

Miscellaneous Deposits

There are four more or less isolated land form-parent material types to be considered under this heading. They are: Muck and peat basins, Rock Benches, Loess on ground moraine and Cemented Tills.

Muck and Peat Basins. Muck and peat are two types of soils which have very low mineral content and correspondingly high organic content, ranging almost to 100 percent. These soils are found in basins in both the ground moraine and the outwash plain, and may be rarely found on the flood plains. They seem to be concentrated more to the southeast section of the county. The depth of the muck and/or peat may range from a few inches to many feet, and their extent is not always clearly indicated on the surface, as mineral soils may have been washed in over them in some cases. These soils usually require some form of special treatment if they are to be used for construction, and for this reason their extent should be quite clearly known. The attached map (Figure A2) shows only the location of the major deposits. Small basins may exist and all basins should be field checked.

Benches. A bench is a type of terrace along a river in which the material forming the area is rock instead of unconsolidated material.



ENGINEERING SOILS MAP
CARROLL COUNTY
INDIANA
PREPARED FROM
1952 AERIAL PHOTOGRAPHS
BY
PURDUE UNIVERSITY
JOINT HIGHWAY RESEARCH PROJECT
IN COOPERATION WITH
BUREAU OF PUBLIC ROADS
SOIL CONSERVATION SERVICE
1966

SCALE OF MILES
3/4 1/2 1/4 0 1 2 3 4

FIGURE A2. ENGINEERING SOILS MAP OF CARROLL COUNTY.

The town of Delphi is built upon one such bench. In this case it was observed that in several places the bedrock, which is limestone, was covered by only a foot or two of alluvium. The depth to rock in this area is somewhat unpredictable, however, and other areas were noted in which rock did not appear at a depth of several feet. Investigation should be undertaken on this bench to determine the depth of this rock.

The overlying material is chiefly sands and silts of the alluvium; any residual soils on the limestone have been removed by erosion.

Loess on Ground Moraine. Several areas in the northeastern part of the county were noted to have an anomalous airphoto pattern. It was determined with the aid of the Agricultural Soil Survey Map that these were areas of Russell soils. This soil is characterized by having 18 inches to three feet of loess overlying ground moraine. These areas have been indicated on the map by varying the textural symbol superimposed on the ground moraine. In these areas the top layer will be a silt, characterized by excellent vertical drainage. The material is of an extremely uniform grain size, and may for that reason be somewhat difficult to compact. The underlying material is of variable grain size, as described under the appropriate sections in the foregoing discussion. It is possible that in certain instances the loess blanket may conceal an area of muck or peat; this should be suspected if an area of unusually poor drainage is noted.

Cemented Tills. In certain areas along the valley walls of the Tippecanoe River it was noted that cemented tills outcropped. These are ordinary outwash or till materials which have been cemented by calcium carbonate. They form layers within the till in some areas. These

cemented tills display all of the characteristics of a rock, and may be difficult to break up with ordinary earthmoving equipment. In cases where it is necessary to make a deep cut in a valley wall, it is recommended that the possibility of striking this type of formation be taken into consideration. There are at least two layers of this material in some places.

LIST OF REFERENCES

1. "The Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes," AASHO Designation M 145-49.

2. Fenneman, N. M., Physiography of Eastern United States, McGraw-Hill Book Company, New York, 1938.

3. Flint, R. F., Glacial and Pleistocene Geology. John Wiley & Sons, Inc., New York, 1957.

4. Logan, N. W., "The Subsurface Strata of Indiana," Publication No. 108, Division of Geology, Department of Conservation, Indianapolis, 1931.

5. Rand McNally Road Atlas, (42nd Annual Edition), Rand McNally & Co., Chicago, 1966.

6. Soils Manual, (2nd Edition), The Asphalt Institute, College Park, Maryland, 1963.

7. "Soils Survey of Carroll County, Indiana," United States Department of Agriculture, Soil Conservation Service, Washington, 1958.

8. Thornbury, W. D., Principles of Geomorphology, John Wiley & Sons, Inc., New York, 1954.

9. "The Unified Soil Classification System," Technical Memorandum No. 3-357, (Vol. 1), Waterways Experiment Station, Corps of Engineers.

10. Woods, K. B., et alia, Highway Engineering Handbook, McGraw-Hill Book Co., New York, 1960.

APPENDIX B

APPENDIX B

THE AIRPHOTO INTERPRETATION OF ENGINEERING SOILS OF WHITE COUNTY, INDIANA

Introduction

The preliminary engineering soils map of White County was prepared as a part of the research discussed in the thesis of James C. Hall, published in January, 1967, and entitled Preliminary Engineering Soils Maps from Small Scale Aerial Photography. The purpose of this report is to supplement the map, providing miscellaneous information which could not be placed on the map.

The original map manuscript was prepared as part of an experimental mapping project making use of 1:69,000 scale aerial photography flown originally for the United States Army Map Service. This photography was used for the interpretation and identification of the engineering land form-parent material groups and engineering soils groups, for determining their boundaries, and in conjunction with a plotter for plotting the boundaries on a base map. A double projection plotter of the Kelsh type, equipped with a pantograph, was used for the map compilation and for some of the interpretation and identification.

A number of other materials were used to assist and supplement the aerial photography both in the interpretation and identification of the soils and in the preparation of the map. These other materials

included the 1:20,000 scale aerial photography available from the Department of Agriculture for additional photographic coverage. The Danville map (NK-6-11) of the Army Map Service 1:250,000 scale 1° by 2° map set was used for initial location. The 1:24,000 scale 7-1/2-minute series topographic quadrangles available from the United States Geological Survey was used for control and for interpretation in some cases. Information concerning the soils was derived in part from the Agricultural Soil Survey map of White County, prepared by the Department of Soils (now Soil Conservation Service) of the Department of Agriculture (11). This was supplemented by the Interstate Route 65 soil report (4) and by field checking in many cases.

The data concerning particle sizes were extracted from the Agricultural Soil Survey and the Interstate profiles, supplemented by field checks. These data are not intended to be considered as anything but an estimate, and as such engineering projects in this county should include detailed field exploration. The subdivision of soils into groups was limited to textural groups associated with land forms and parent materials, with a few exceptions. The most notable of these are the areas of loess overlying glacial drift, and the areas of muck, peat, and highly organic topsoil. An effort was made to delineate the larger examples of these soil groups.

Description of Area

General

White County is located in the northwestern part of Indiana. The location and shape are illustrated in Figure A3. It has a total area of

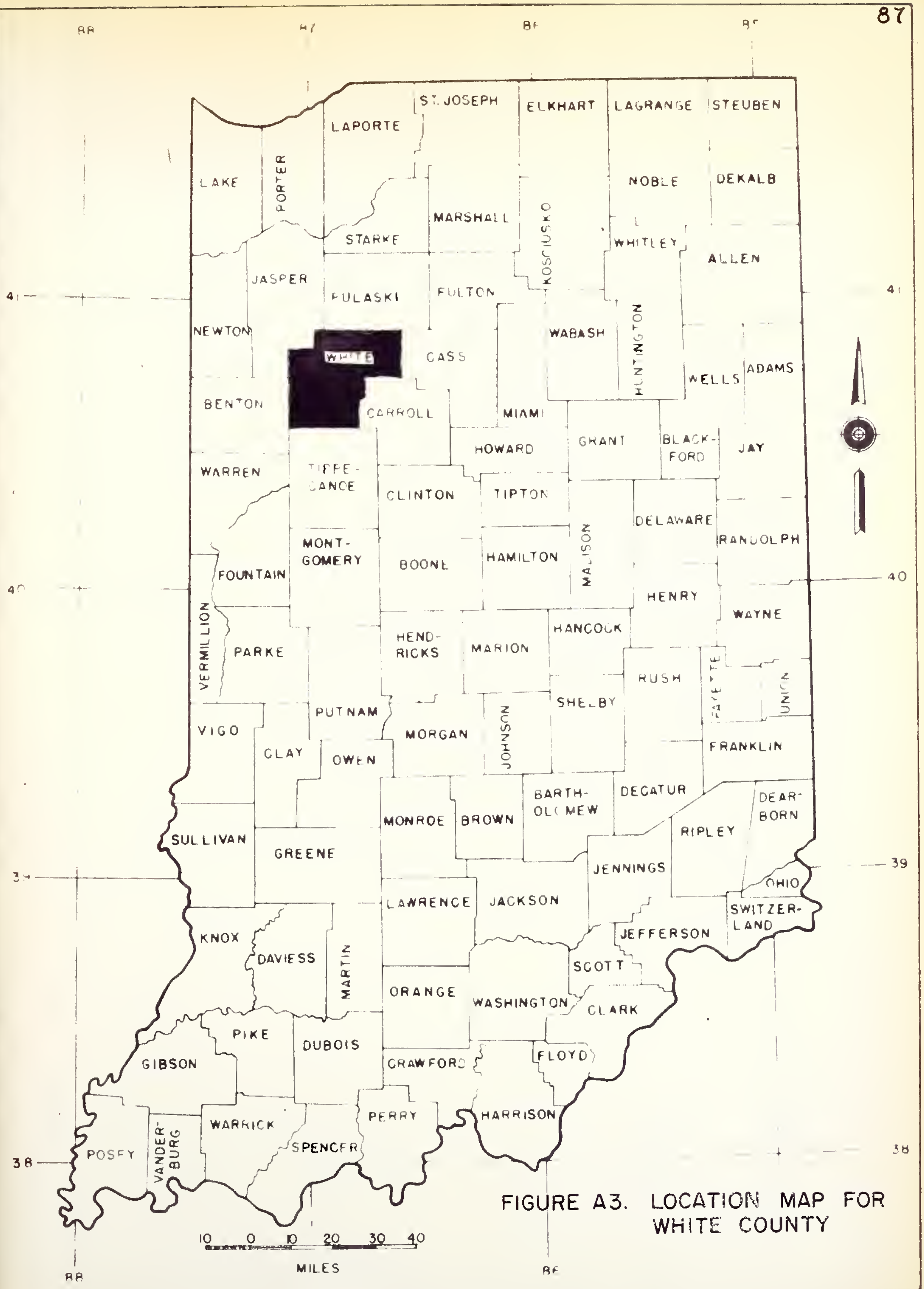


FIGURE A3. LOCATION MAP FOR WHITE COUNTY

about 502 square miles. The total population in the 1960 census was 19,709 people, of whom 4,035 lived in Monticello (6). Monticello is the county seat, and is located on the west bank of the Tippecanoe River about halfway between the north and south borders. Other large towns include Monon, 1,417, in the northern part of the county, and Brookston, 1,202, in the southern part of the county (6). The remainder of the population either lives in centers with a population of less than 1,000, or on farms. The economy of the area is based almost entirely on farming, although there is some light industry in Monticello and Monon.

Drainage Features

The drainage of White County is dominated by the Tippecanoe River which flows south through the middle of the northern half of the county and forms part of the eastern boundary of the southern half of the county. The Tippecanoe River has a number of small tributaries which meander sluggishly across the upland plains in a very poorly integrated pattern. These tributaries drop rather steeply into the valley of the Tippecanoe. This natural drainage system is supplemented by a number of artificial ditches, particularly in the western part. These ditches were constructed in an effort to improve the vary poor natural drainage.

There are no large natural lakes in this county. Many of the farms have their own ponds, most of which have been made by excavation. A few farm ponds may be in part natural, however. The Tippecanoe River has been dammed for hydroelectric power in two places, and the two lakes thus formed, Lake Freeman and Lake Shafer, provide excellent recreational facilities for a large portion of north-central Indiana.

Topography

The topography of White County is a level plain at an elevation of about 700 feet above sea level. Other features have been superimposed on this plain. In the southern part of the county the relief on this plain is generally less than about 10 feet. There are some minor valleys, with the dissection increasing slightly toward the east. In the southwestern part there is a low esker or crevasse filling with a total relief of about 20 feet. In the area north and east of Brookston a sizable kame complex breaks the monotony of the plain. This is the only significant ridge moraine area in the county. The local relief here is about 40 feet. These hills, which are quite easily noticed from either of the main highways through Brookston, are also the most significant positive relief features in the county.

The northern part of the county is marked by a series of very sizable dune complexes. These dunes may be 30 or more feet high. They are built on the same low rolling plain as exists in the remainder of the area. They give the northern part of the county a somewhat more rolling aspect, however. These dune complexes often rise quite abruptly from the surrounding plains. They have a generally east northeast trend.

The only significant valley is associated with the Tippecanoe River, which is about 40 feet deep. This valley is in a large part filled with the two lakes mentioned earlier. The only steep slopes in the county are found in the valley walls along the Tippecanoe River and major tributaries.

Geology

The surface of White County is dominated by glacial drift, although the topographically significant dune complexes have been noted. This till was contributed by the Lake Michigan, the Saginaw, and the Lake Erie lobes of the Wisconsin ice sheets, although the Lake Michigan lobe may have been dominant (3). It is believed that this ice left the region 10,000 to 15,000 years ago (3). The hill complex near Brookston is probably a portion of a recessional moraine. Like the Bloomington moraine farther southwest, however, this moraine appears to consist of a discontinuous series of kames and knolls. The areas in between these kames do not appear to differ significantly from the ground moraine, and were therefore not mapped separately.

The eolian sands in the north were probably derived mostly from outwash deposits in the Kankakee River valley spillway farther to the north, although some may have been contributed from other spillways. Although the dunes are now anchored by vegetation, at one time they must have constituted quite a large and active field. They still are subject to movement if the vegetation is disturbed.

There is a small amount of outwash in the Tippecanoe River valley. This is probably mostly overflow from the Wabash River spillway, but some of it may have come from the north.

The bedrock surface in this county appears to vary from rolling in the east to fairly level on the west. It was noted that the bedrock does not actually outcrop anywhere in the county, although it lies quite close to the surface in many areas. In the eastern part of the county, the topography of the bedrock surface is probably dominated by the

proximity of the valley of the Teays River, a pre-glacial stream somewhat larger than the present Ohio River (3). This would give the bedrock surface here a somewhat rolling aspect. In the west, however, it appears from the borings for Interstate Route 65 (4) that the bedrock lies within about 10 feet of the surface in many places. The rock in this area is a shale of Devonian age; in many of the borings it appears that it grades smoothly into the ground moraine above it, or at least that the boundary is somewhat diffuse. This shale is poorly consolidated. In the eastern part of the county, in the valley of the Tippecanoe River, bedrock again may be close to the surface. At this elevation it is likely that the rock would be a Silurian limestone. This rock is well consolidated, but is apt to be rather high in chert.

Land Forms and Engineering Soil Areas

The land form-parent material groups and engineering soils areas of White County may be conveniently divided into four groups for the purposes of description. These groups are: the glacial deposits, the fluvial and glacio-fluvial deposits, the eolian deposits, and miscellaneous deposits. Further subdivisions will be noted as they occur.

Glacial Deposits

Glacial deposits underlie the entire area of White County except for sections within river valleys. They also constitute the surface soils over the majority of the area. They are all very poorly sorted, and are in general very high in fines. They divide into two groups; the ridge moraines and the ground moraines.

Ridge Moraine. In the southeastern part of the county, northeast of Brookston, there is a sizable hill complex forming a ridge moraine. The relief is on the order of 40 feet, with a number of fairly steep slopes. The soils consist of particles of virtually every size, from the finest clays to boulders. The dominant grain size is a silt, and the soils are characterized as being silt loams or silty clay loams. The low areas may have a fairly high organic content, but the high ground is quite clear of organic material. The erosion may be a problem on the steep slopes, and the clay fraction tends to be reduced in these areas.

Construction across this area is somewhat complicated by the steep slopes, which would necessitate quite a bit of cut and fill. The native material is not particularly well suited to construction, as it was noted that it seemed somewhat plastic. Also it is very doubtful that a suitable source of gravel could be developed in this area, as the material appeared to be very poorly sorted and it was noted that water stood in areas throughout the complex, indicating that the internal drainage was rather poor.

Ground Moraine. The ground moraine in this county is very poorly sorted. It is characterized chiefly as being silty clay loam or silty clay. The underlying soils tend to have a fair concentration of cobbles and boulders. These are deep enough that they do not appear on the surface in any great quantity, but they were noted in many of the drainage ditches in the southern part of the county, and also in the bed of a stream near Brookston. It appeared that the first seven or eight feet of the profile was free of these stones, however, and was limited to gravel sizes or smaller.

The relief on the ground moraine is very low, and in fact it appears to be relatively flat. In spite of this very low relief, the topographic position of the sample makes a sizable difference in its characteristics in the upper horizons. The soils in the higher places are generally a yellow-brown color, and have a fairly low concentration of organic material. It was noted that the silt fraction of these soils tend to blow away. The soils on the very gentle slopes are very similar, but seemed to be slightly lower in clay and organic matter. In the low swales, which serve as surface drainage ways, the internal drainage being very poor, the organic content is higher, and the clay fraction becomes predominant. These soils are a dark brown, do not blow, and appear to be fairly plastic. In certain areas these soils grade into soils which, while still having an appreciable mineral content, are very plastic and very high in organic matter. Muck or peat, which is treated separately, may appear in some areas.

The parent material is fairly uniform throughout the entire area. The particle size is predominantly in the silt-clay range, although fragments up to gravel are not uncommon. In certain areas the boulders may be in high concentration, but the extent of these areas is not known. The boulders were noted in the area around Brookston, primarily. The internal drainage of the ground moraine is very poor, and field drainage tile is quite common.

The chief construction problems in the ground moraine would be the fact that construction materials and aggregate appear to be quite nonexistent and the problem of providing adequate drainage.

Fluvial and Glacio-Fluvial Deposits

Fluvial and glacio-fluvial materials do not occur over large areas in White County, but are confined to the immediate vicinity of the Tippecanoe River and some of its tributaries.

Flood Plains. The area of alluvium in flood plains in this county appears to be quite confined. The alluvial materials are principally silts, but larger particle sizes do occur. The materials in this class are all quite well sorted, although they lens in and out somewhat unpredictably. It is likely that some of these areas may have usable amounts of gravel in them, although in one pit which was studied, located near Springboro, it did not appear that the gravel was particularly clean. It is also believed that the gravel, where it exists, is liable to be quite cherty. It was noted that the beds of many of the streams in the southern portion of the county, as well as the Tippecanoe River itself, had a fairly high amount of the boulder and cobble material noted in the ground moraine.

The drainage in these fluvial materials is liable to be fair to good, although the water table is likely to be high due to the proximity of the streams.

The construction problems are associated with flooding. Obtaining a proper foundation for a structure may pose a problem due to the uniformity of size of the particles in some areas.

Outwash Plain. A small amount of what is labeled outwash plain was noted. On a field inspection trip, it was noted that the material in this area very closely resembled the adjoining ground moraine areas, with the exception that there was slightly less of the clay fraction in evidence.

The material exhibits a crude stratification, but in other respects is most similar to the ground moraine and the discussion of that is felt to apply to this. It is quite likely that, while these deposits appear superficially to be outwash, they are probably areas in which the ground moraine has been reworked by water, and are not truly areas of water-deposited material.

Eolian Deposits

Eolian deposits are quite wide-spread in this county. They may be divided into three sub-groups: Sand dunes, sand over ground moraine, and silt over ground moraine.

Sand Dunes. Much of the northern part of the county is covered with large dune complexes. The topography is generally crested, as is characteristic of dunes. Not all of the area delineated as sand dunes is covered with sand; it was noted that interdune areas may be the underlying till and may even be muck in places. Small interdune areas could not be delineated on the map. However, the majority of the area is covered by dunes.

These dunes are composed of a medium to fine sand. The particles are all of a narrow range of size, for all practical purposes. Although these dunes are now anchored by vegetation in most cases, they are subject to blowing if the vegetation is disturbed. The vegetation is chiefly grasses, low shrubs, and trees, such as the oak. In general the dunes are not farmed, due to both their tendency to blow and due to the excellent internal drainage, which tends to make them droughty.

There are two main problems anticipated in construction in these areas. The first is that some provision must be made for stabilizing the slopes of the cuts which have to be made to get across the dunes. Several examples of locations where the sand had blown completely across paved secondary roads were noted on a field expedition. The second problem is that compacting these soils may be difficult, unless they are confined in some way. Drainage on the dunes themselves is excellent, although rarely the interdune areas may present drainage problems.

Sand Over Ground Moraine. In a number of the areas adjacent to the sand dunes, a thin layer of sand was noted overlying the glacial drift. This was particularly true of the areas between the dune complexes. This sand layer is not thick, averaging less than a foot, and it was noted that deep plowing brought the underlying till to the surface. It should be noted that the sand may in certain cases tend to obscure the locations of muck pockets.

Loess Over Ground Moraine. In the eastern part of the county an area of loess over ground moraine was noted. It was observed in the field that the layer was thin, being generally less than three feet. Since this is deep enough to cause some problems in compaction, however, the area is separated. The underlying material in this area is believed to be till; certainly its composition is similar to till.

Miscellaneous Deposits

There are two types of material which have not been covered previously, but which are locally somewhat important. These two are the basins of muck and peat, found in many areas, and layers of conglomerate ledges, which were noted in some of the valley walls.

Muck and Peat Basins. Soils which are very low in mineral content, very plastic, and very poorly drained are encountered in many localities throughout the county. They are particularly common in the ground moraine in the southwest, but another area exists east of Monticello in the ground moraine. They were also noted in some of the interdune areas.

The depth and extent of the muck and peat basins is somewhat difficult to predict without checking them individually. Many of the ones which were noted during a field trip appeared to be quite shallow, as plowing had brought up the underlying mineral soils. However, it is known that these pockets of material may be quite deep. Furthermore, it is possible in some areas. particularly in the dune areas, that some of these pockets have been partly concealed under mineral material which has blown or washed in.

The chief problem which these areas present is that they are subject to unpredictable settlement. They are also quite plastic and difficult to compact. For these reasons, special treatment of these areas may be called for.

Cemented Tills. In some areas along the banks of the Tippecanoe River, outcrops of cemented tills were observed. These are beds which have been cemented into a rock-like material by calcium carbonate. In the particular outcrop studied, the material was about two feet thick, and quite hard. It appeared that there were at least two levels, separated by 10 or 15 feet. This material is hard enough that it is believed that it might give some trouble to ordinary earthmoving equipment, and consideration should be made of its existence if a project which involves a deep cut through a valley wall is contemplated.

LIST OF REFERENCES

1. "The Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes," AASHO Designation M 145-49.

2. Fenneman, N. M., Physiography of Eastern United States, McGraw-Hill Book Company, New York, 1938.

3. Flint, R. F., Glacial and Pleistocene Geology, John Wiley & Sons, Inc., New York, 1957.

4. Interstate Route 65 Soil Profiles in White County, (2 volumes), American Testing and Engineering Co., (unpublished), 1965.

5. Logan, N. W., "The Subsurface Strata of Indiana," Handbook of Indiana Geology, Department of Conservation, Indianapolis. 1931.

6. Rand McNally Road Atlas, (42nd Annual Edition), Rand McNally & Co., Chicago, 1966.

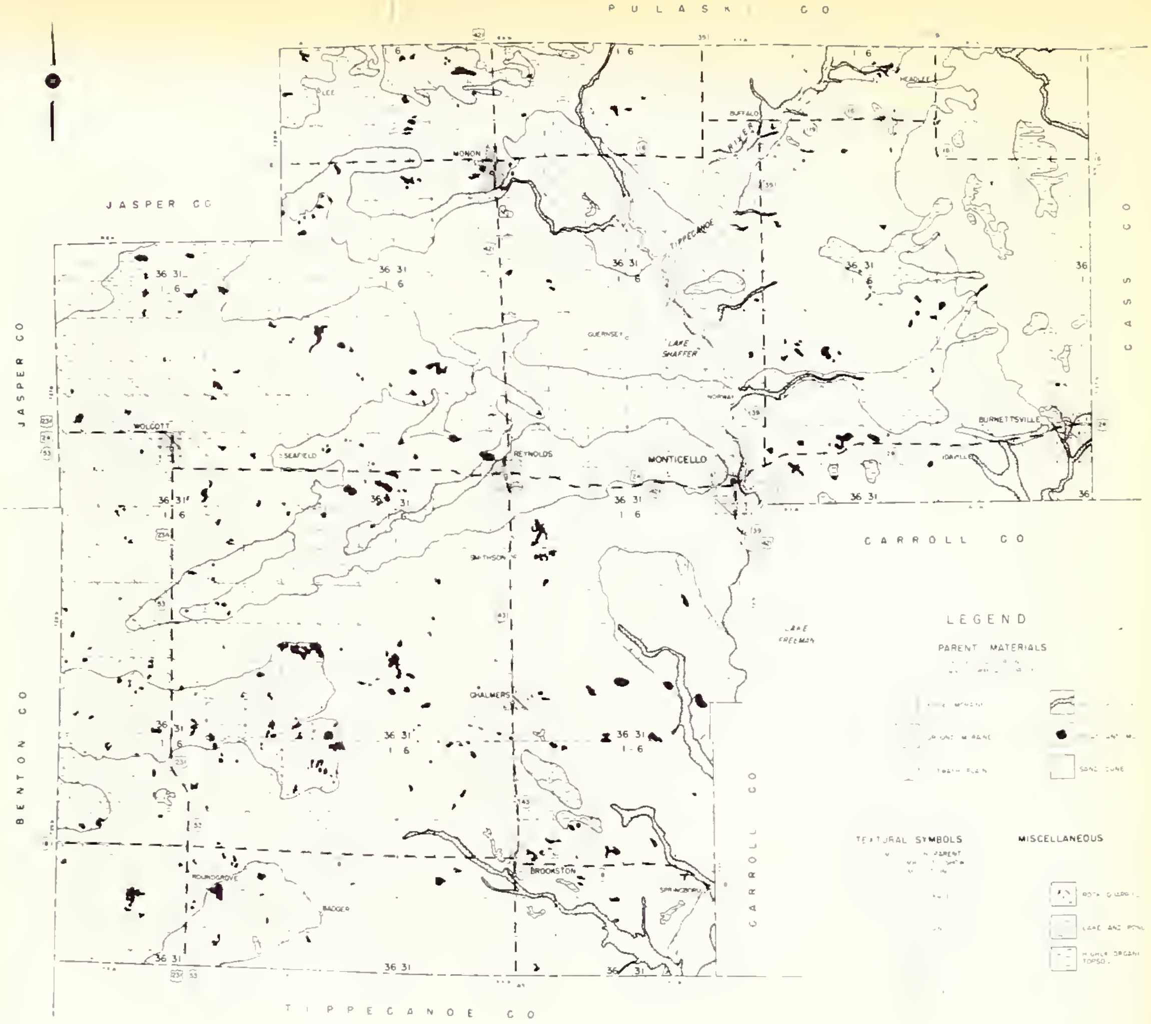
7. Soils Manual, (2nd Edition), The Asphalt Institute, College Park, Md., 1963.

8. Thornbury, William D., Principles of Geomorphology, John Wiley & Sons, Inc., New York, 1954.

9. "The Unified Soil Classification System," Technical Memorandum No. 3-357, (Vol. 1), Waterways Experiment Station, Corps of Engineers.

10. Woods, K. B. et alia, Highway Engineering Handbook, McGraw-Hill Book Co., New York, 1960.

11. "Soil Survey of White County, Indiana," United States Department of Agriculture, Department of Soils (now Soil Conservation Service), Washington, 1915.

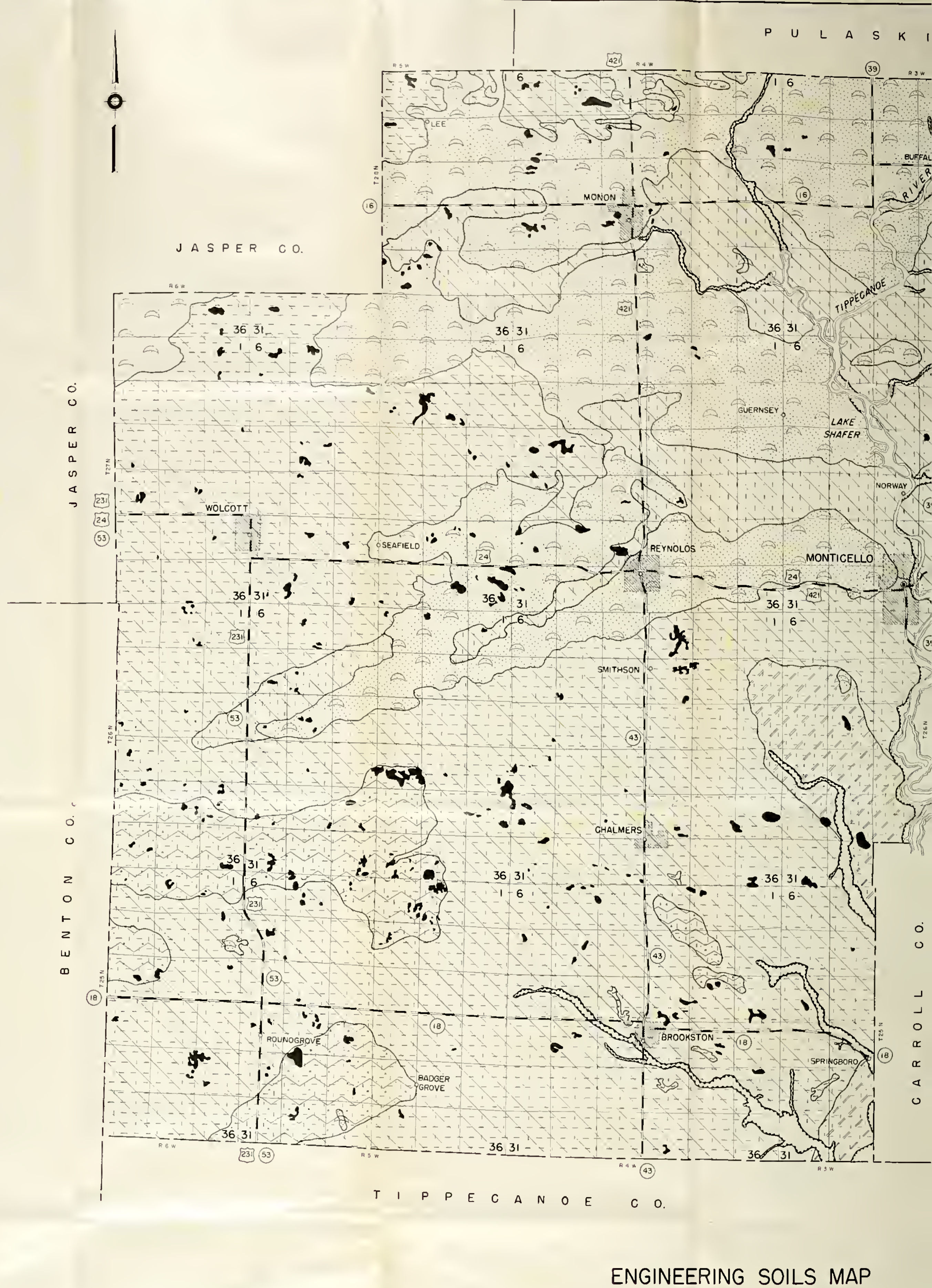


ENGINEERING SOILS MAP
WHITE COUNTY
INDIANA
PREPARED FROM
1952 AERIAL PHOTOGRAPH
PURDUE UNIVERSITY
JOINT HIGHWAY RESEARCH PROJECT
BUREAU OF PUBLIC ROADS
SOIL CONSERVATION SERVICE
1966

FIGURE A 4. ENGINEERING SOILS MAP OF WHITE COUNTY.

JHRP 67/8 2 plates

1. Carroll County 2 White County



ENGINEERING SOILS MAP

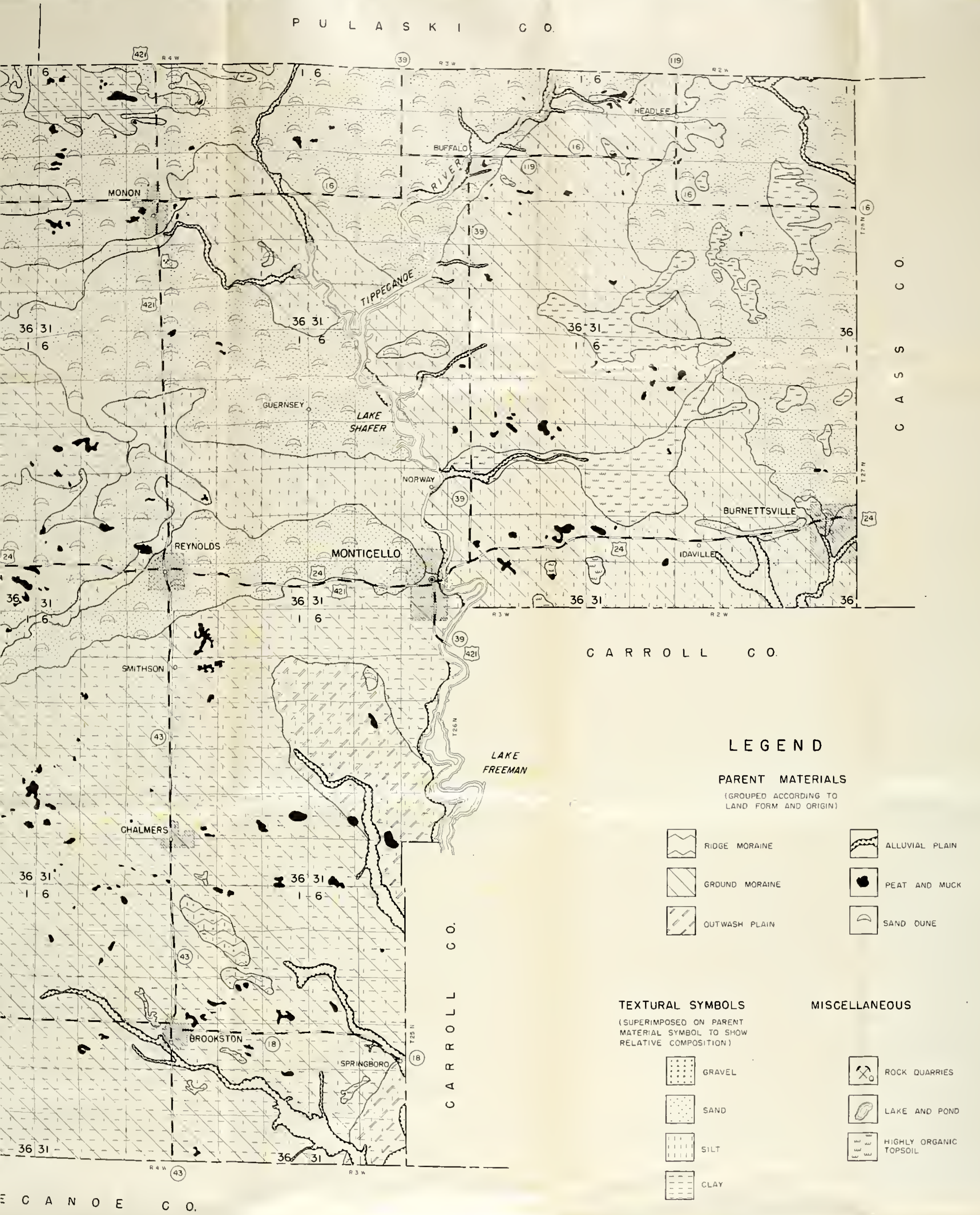
WHITE COUNTY

INDIANA

PREPARED FROM
1952 AERIAL PHOTOGRAPHS
BY
PURDUE UNIVERSITY
JOINT HIGHWAY RESEARCH PROJECT
IN COOPERATION WITH
BUREAU OF PUBLIC ROADS
SOIL CONSERVATION SERVICE
1966

SCALE OF MILES
3/4 1/2 1/4 0 1 2 3 4

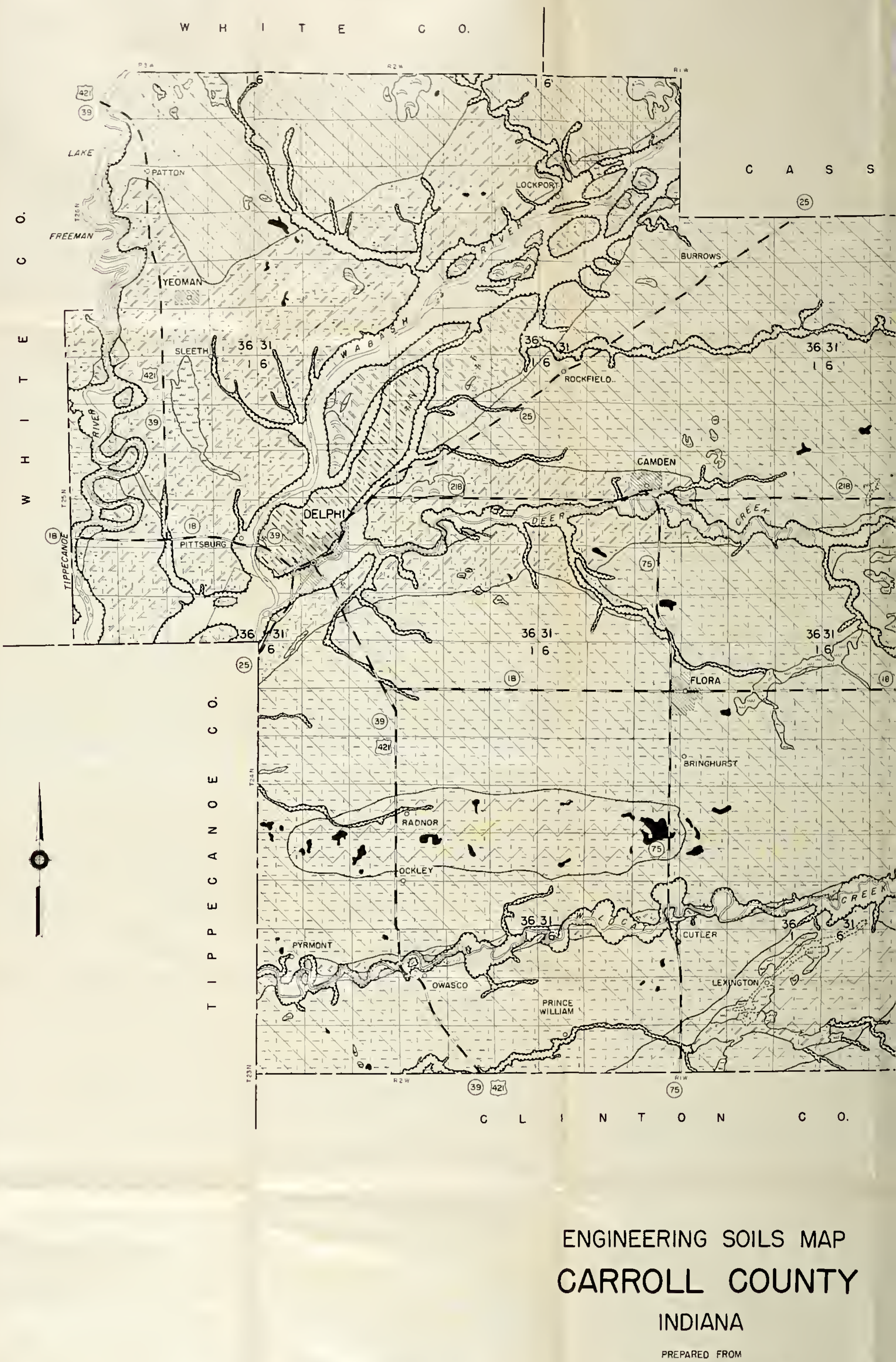
PREPARED UNDER THE SUPERVISION OF: R. D. MILES AND . C HALL



ENGINEERING SOILS MAP
WHITE COUNTY
INDIANA

PREPARED FROM
1952 AERIAL PHOTOGRAPHS
BY
PURDUE UNIVERSITY
JOINT HIGHWAY RESEARCH PROJECT
IN COOPERATION WITH
BUREAU OF PUBLIC ROADS
SOIL CONSERVATION SERVICE
1966

DRAWN BY Y. K. TANG



ENGINEERING SOILS MAP

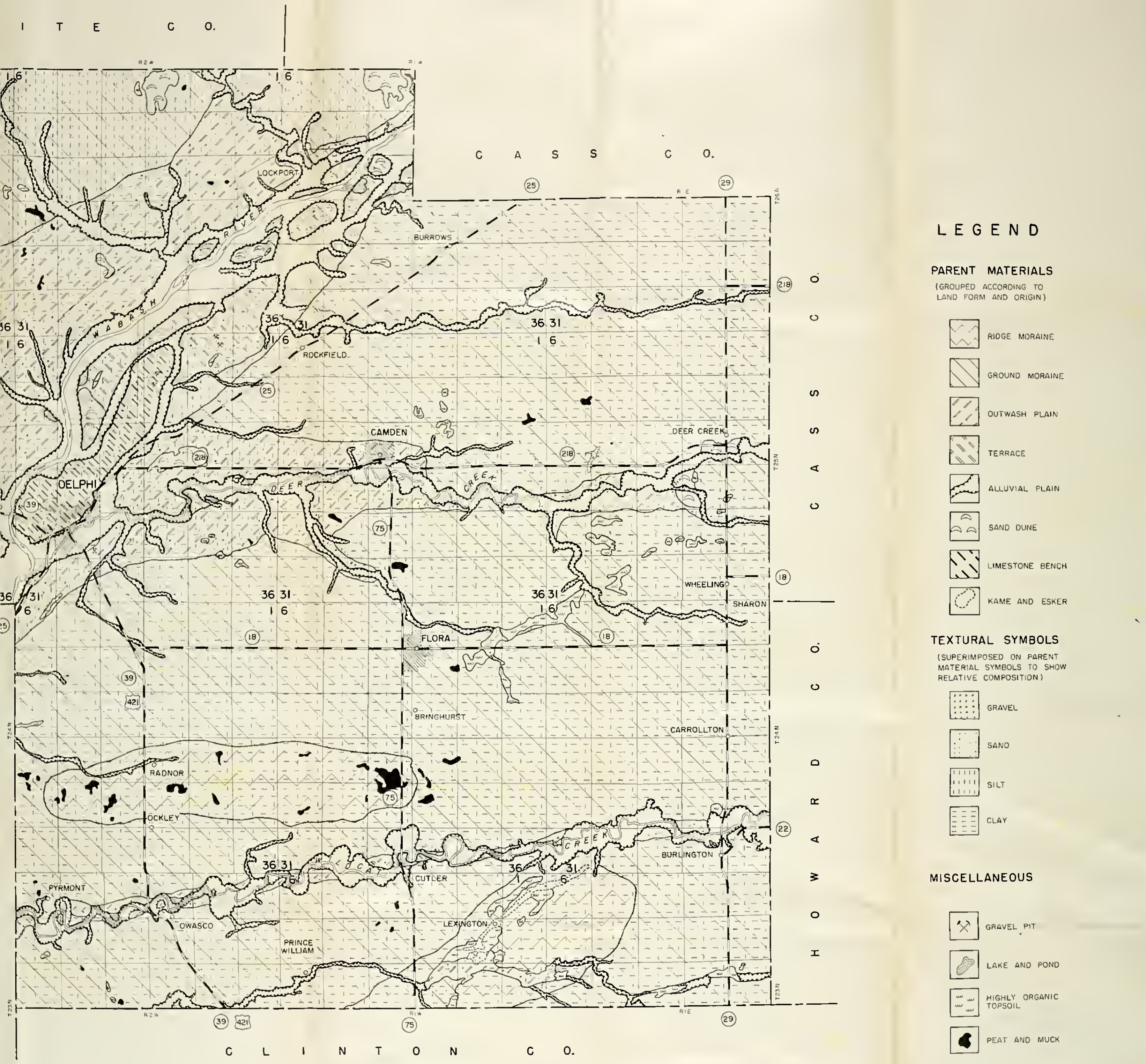
CARROLL COUNTY

INDIANA

PREPARED FROM
1952 AERIAL PHOTOGRAPHS
BY
PURDUE UNIVERSITY
JOINT HIGHWAY RESEARCH PROJECT
IN COOPERATION WITH
BUREAU OF PUBLIC ROADS
SOIL CONSERVATION SERVICE
1966

SCALE OF MILES
3/4 1/2 1/4 0 1 2 3 4

PREPARED UNDER THE SUPERVISION OF: R. D. MILES AND J. C. HALL



ENGINEERING SOILS MAP

CARROLL COUNTY

INDIANA

PREPARED FROM

1952 AERIAL PHOTOGRAPHS

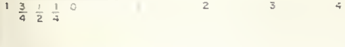
BY

PURDUE UNIVERSITY
JOINT HIGHWAY RESEARCH PROJECT

IN COOPERATION WITH

BUREAU OF PUBLIC ROADS
SOIL CONSERVATION SERVICE

1966



DRAWN BY: Y K TANG